

**Bond University**

## **DOCTORAL THESIS**

### **The Impact of Supply Chains on Productivity and Financial Performance of Power Producers in Australia.**

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*Award date:*  
2017

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**The Impact of Supply Chains on  
Productivity and Financial Performance of  
Power Producers in Australia.**

**Nedal Aburadi**

**The thesis submitted in fulfilment for the requirements of the  
degree of Doctor of Philosophy**

**Bond University  
Faculty of Society & Design**

**November 2016**

# **Abstract**

Over the past 10-20 years, Australian federal and state governments have introduced dramatic changes to the Australian power generation market to boost competitiveness and aid with the rapid development of the Australian power generation industry and businesses. These changes included the deregulation, disaggregation and privatisation of the power generation companies and supply chains, resulting in the formation of a new regulatory and management framework called the National Electricity Market.

As a result, a variety of different strongly heterogeneous power providers and market operators have emerged in Australia, drastically changing the business environment and causing significant gaps in our understanding of how to manage and regulate this environment in an efficient way. In addition, there are also significant consumer trends to embrace a variety of off-grid renewable power sources in combination with rapidly improving storage technologies. This may certainly have a significant impact on any centralised power generation/distribution companies. There is currently a need to evaluate the impacts of these revolutionary processes on the performance of power generation industry in Australia to boost its competitiveness and consumer orientation.

Therefore, this research uses cluster analysis, mixed effect regressions and generalised structural equation modelling to develop and apply comprehensive statistical approaches in order to reasonably categorise highly diverse electricity

generating/supplying companies and study any existing average productivity trends and dependences on other performance variables characterising the production process and size of the involved companies. It is demonstrated that there are two major clusters and four distinct groups (smaller clusters) of companies and supply chains on the Australian power generation market with different performance and productivity trends. One of the significant findings is that there was a significant general trend of declining productivity by around 15% – 20% over the observation period between 2007 and 2012 for all company categories. At the same time, the considered case studies involving several successful companies also showed that this general negative productivity trend could be overcome through proper managerial decisions and approaches.

Another determined general trend (with the exception of a few successful companies) was that smaller supply chains and companies appear to be more efficient in terms of their labour and capital productivities. This trend defied some of the previous (though quite limited) findings that optimal productivity might be achieved with larger companies. Simple approximate criteria were derived in this study, based on the determination of the critical values of Property Plant and Equipment (PP&E) and Employee Cost (EC). Companies with PP&E < \$1 – \$2 billion and EC < \$50 – \$75 million per year tend to have (on average) higher productivities and are more sensitive to changing their size in the form capital assets and labour cost. Significant direct and indirect effects of the considered performance variables on company energy output and productivities were also identified and analysed using the path analysis in the generalised structural equation model.

The conducted research has thus made significant contributions to the existing knowledge and methodologies for the analysis of average productivity trends in a

significantly heterogeneous sample of production units/companies on the market, including the statistically based clustering of the heterogeneous production entities and their subsequent analysis by way of the generalised structural equation modelling to establish and quantify the networks of causal relationships between the productivity-related performance variables and factors.

Specific recommendations for the regulating authorities and company management were proposed. These included the need for different managerial approaches in different company groups/categories, different recommended company sizes, managerial approaches to overcome the general negative productivity trends on the power generation market, and the need for government support to ensure the successful transition to renewable energy sources.

# Declaration

This dissertation is submitted to Bond University in fulfilment of the requirements of the degree of Doctor of Philosophy. This thesis represents my own original work towards this research degree and contains no material which has been previously submitted for a degree or diploma at this University or any other institution, except where due acknowledgement is made.

01/09/2015

Nedal Aburadi

Date

# Acknowledgements

I would like to thank all the people who contributed in some way to the work described in this thesis. First, I would like to express my sincere gratitude to my advisor Professor Michael Regan for the continuous support during my PhD study and related research and for his patience, motivation, and immense knowledge. His guidance helped me in all the time I spent research and writing this thesis. I could not have imagined having a better advisor and mentor for my PhD studies. Without him, this thesis would not have been completed or written. One simply could not wish for a better or friendlier supervisor.

I would like to thank my parents for their material and spiritual support in all aspects of my life. I also would like to thank my brothers, sisters for the assistance they provided to me in numerous ways.

I want to express my gratitude to my lovely sweet daughter, Jwan. Finally, a person that moved with me to Australia, leaving her family and friends because of it, my lovely wife, dear Rawan. Without your support and encouragement, I could not have finished this work. It was you who kept the fundamentals of our family, and I understand it was difficult for you, therefore, I can just say thanks for everything and may God give you all the best in return.

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# List of Abbreviations:

**ABS:** Australian Bureau of Statistics

**AER:** Australian Energy Regulator

**ASX:** Australian Securities Exchange

**CEO:** Chief Executive Officer

**D:** Distribution

**DEA:** Data Envelopment Analysis

**EBIT:** Earnings Before Interest and Tax

**EBITDA:** Earnings Before Interest, Taxes, Depreciation, and Amortisation

**EC:** Employee Cost

**EGDC:** electricity generating and/or distributing company

**EN:** Employee Number

**ESAA:** Energy Supply Association of Australia

**G:** Generation

**GD:** Generation and Distribution

**GHG:** Greenhouse Gas

**GL:** Gigalitre

**GSEM:** Generalised Structural Equation Model

**GW:** Gigawatt

**GWh:** Gigawatt-hour

**ID:** Identification number

**IT:** Information Technology

**KNP:** Kosciuszko National Park

**LPG:** Liquefied Petroleum Gas

**MW:** Megawatt

**MWh:** Megawatt-hour

**NEM:** National Electricity Market

**NSW:** New South Wales

**PC:** Principal Component

**PCA:** Principal Component Analysis

**PJ:** Petajoule

**PP&E:** Property, Plant & Equipment

**PV:** Photovoltaic

**RET:** Renewable Energy Targets

**SC:** Supply Chain

**SCM:** Supply Chain Management

**SEM:** Structural Equation Model

**SFA:** Stochastic Frontier Analysis

**StoNED:** Stochastic Non-Smooth Envelopment of Data

**TWh:** terawatt-hour

# Chapter 1. Introduction

One of the significant issues in the Australian economy is the growing infrastructure deficit (Infrastructure Australia, 2013). In 2013, Infrastructure Australia estimated the overall equity value of commercial infrastructure assets held by the Australian Federal and State Governments to exceed \$100 billion (Infrastructure Australia, 2013). Infrastructure Australia also advocated that Australian governments should consider transferring publicly owned infrastructure to the private sector and utilise the net proceeds to build new infrastructure (Infrastructure Australia, 2013). This turnover of government ownership is expected to maintain the required level of continuing government investments in new infrastructure (through the proceeds from the transfer of the existing infrastructure to the private sector), while maintaining and improving the level of services from the previously constructed infrastructure through the private sector ownership (utilising the benefits and advantages offered by the private management).

An alternative way to fund further investments in new infrastructure is for the government to use dividends from publicly owned companies. Although many publicly owned companies do return dividends, the overall returns are typically much lower than those generated in the private sector (Hilmer et al., 1993). In addition, increasing dividends from publicly owned companies could cause adverse public reactions with regard to equity of distribution of the returns. As noted by the Senate Select Committee on State Government Financial Management, *“It is difficult to escape the conclusion that some Government Business Enterprises (GBEs) are being milked for short-term gain at the expense of their medium to long term health. Funds transferred to state governments for recurrent spending*



*cannot be used by enterprises to modernise infrastructure and situate themselves positively for the future*” (Senate Select Committee on State Government Financial Management, Final Report, p.67, 2008; Infrastructure Australia, 2013). This is one of the significant difficulties further limiting efficient operation of publicly owned companies and infrastructure, thus limiting government returns and their capability to invest in new infrastructure. The transfer of existing government assets to the private sector is likely to generate significant proceeds and, thus, substantially greater capacity for governments to invest in new infrastructure. This represents an efficient and natural cycle of government involvement in prioritised infrastructure and economic development. For example, it is estimated that, after taking into account the potential dividends, an additional \$64 billion for new government investments was likely to be generated because of the privatisation of the 30 public sector assets considered by the Infrastructure Australia (2013). In addition, such public ownership turnover should provide natural leveraging for governments to influence the overall developmental trends and economic strategies through targeted investments in new infrastructure.

## **1.1 Evolution of Energy Generation in Australia**

Importantly, amongst the 30 publicly owned assets analysed by Infrastructure Australia (2013), 13 (almost half) were involved in the generation, transmission and distribution of electricity. In addition, the development and performance of the electricity generation and distribution industry in Australia have the capacity of impacting on the performance of a significant number of other vital industries and companies through electricity costs and reliability of supply, which makes the electricity power sector particularly important for the health and performance of the Australian economy as a whole. This illustrates the particular importance and significance of the detailed understanding and

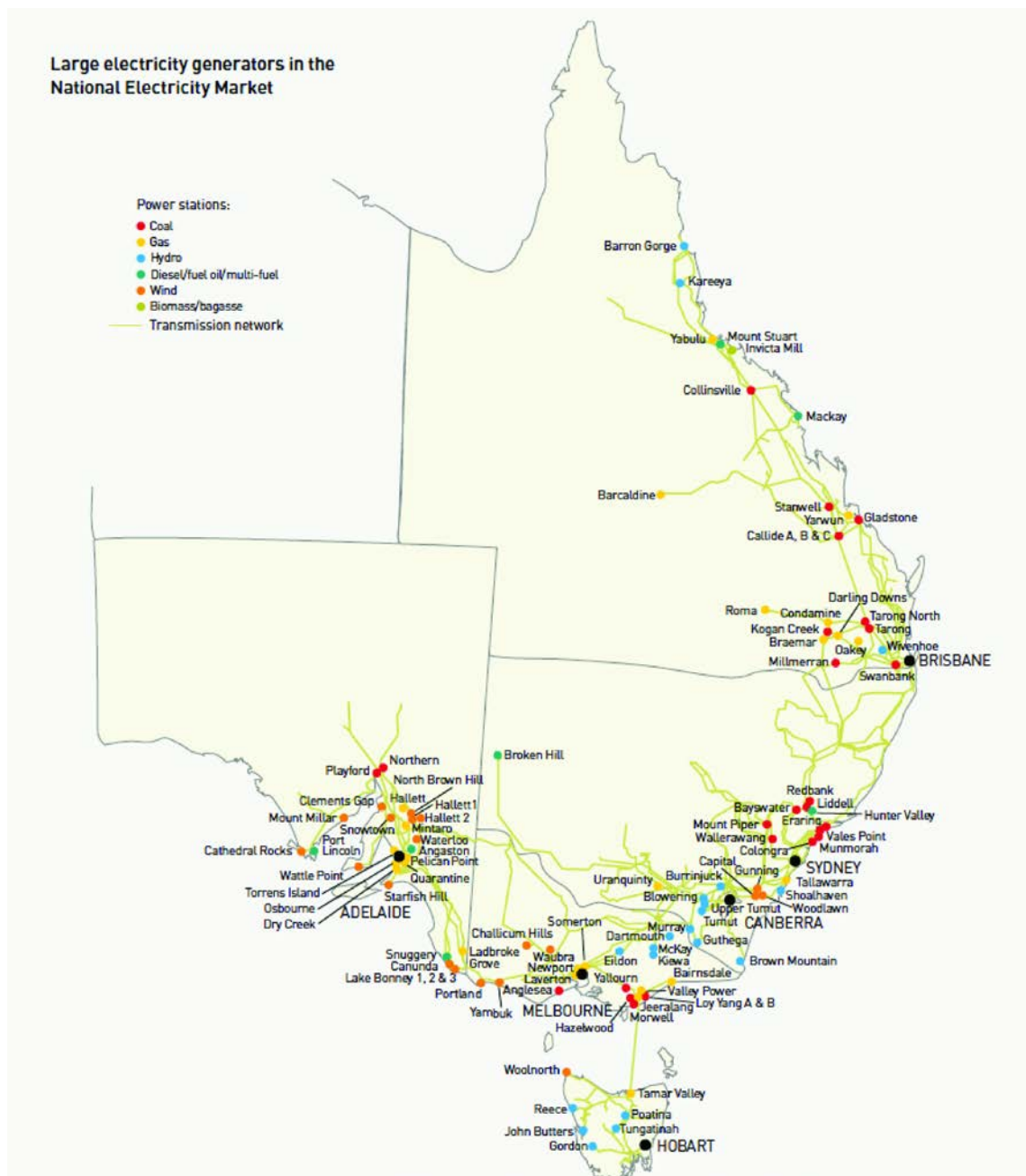
thorough analysis of the electricity energy industry, including the major trends in performance and productivity of the electricity generating and distributing companies.

The wide privatisation, deregulation and disaggregation of this industry (Hilmer et al., 1993) was one of the reasons for the rapid and radical evolution of the Australian power sector, such that it is barely recognisable from what it used to be back in 1990s (Australian Energy Regulator, 2014). These evolutionary processes are continuing today under the external pressures of ongoing changes in the legislative and operating environment, market competition, wholesale price volatility, uncertainties and a significant reduction in the electricity demand (Beder, 2013; Brinsmead et al., 2014; Australian Energy Regulator, 2014; Marketline, 2014).

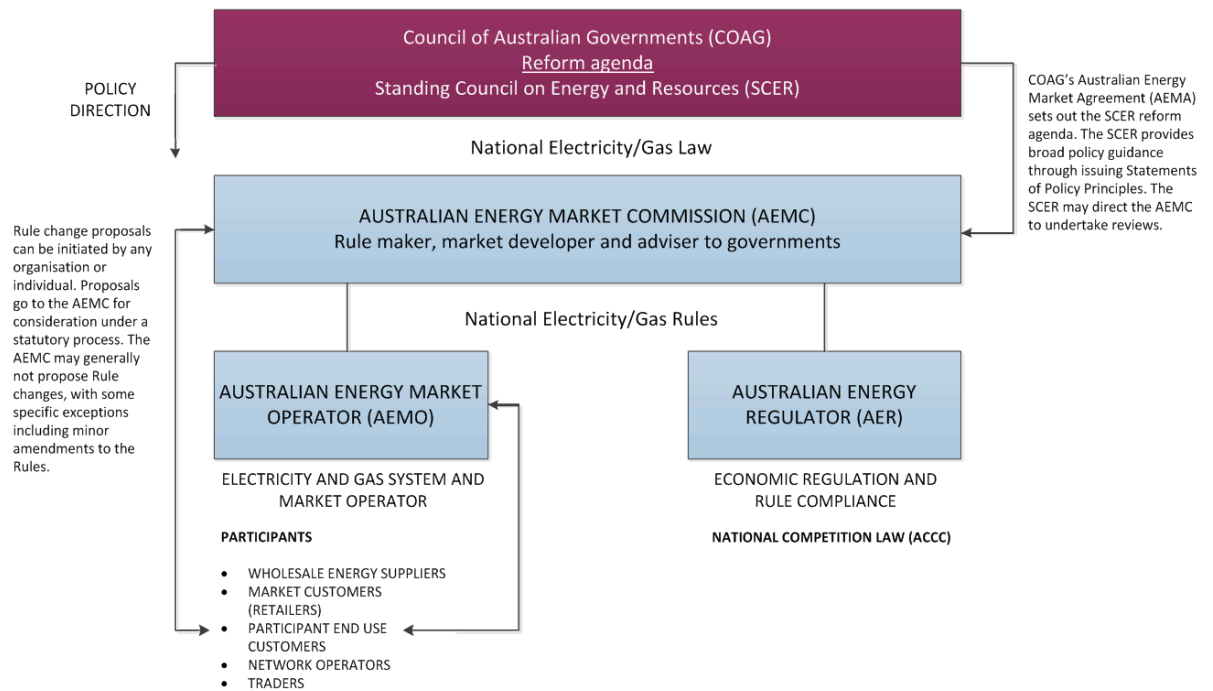
Over the past ten to twenty years, Australian governments have also made considerable effort to encourage trade and, as a result, removed unnecessary regulatory barriers and divisions between states. Today, the energy industry in Australia comprises of numerous generators, distributors and retailers that are competing against each other and simultaneously constituting the National Electricity Market (NEM) – one of the longest single interconnected power systems in the world (Fig. 1.1) (Pierce, 2012; Australian Energy Regulator, 2011). The NEM operates in the form of a competitive spot market where price adjustments occur in real time in line with the demand and supply conditions (Australian Energy Regulator, 2014).

The total NEM output in 2010-2011 was over 204 TWh of power delivered to around 9 million customers. This energy came from 305 generating plants, with a total installed capacity of 49110 MW. The NEM power network incorporates over 750,000 km of distribution and 40,000 km of transmission infrastructure (Pierce, 2012; Australian Government Productivity Commission, 2012). This demonstrates the complexity of the

physical and economic management of the available versatile generation and distribution resources in Australia (Fig. 1.1).



**Figure 1.1.** Generation and transmission map of the NEM extending over 5,000 km along the eastern rim of Australia from Port Douglas in North Queensland to Port Lincoln in South Australia and Hobart in Tasmania (Pierce, 2012; Australian Energy Regulator, 2011).



**Figure 1.2.** The NEM institutions for observation, control and regulation of the commercial and business activities of participating Australian Energy Market Operators, i.e., generation and/or distribution supply chains. Sources: (Pierce, 2012).

One of the significant roles of the NEM is the regulatory function in relation to the electricity generation and/or distribution industry in Australia. The major regulating and policy-making bodies and institutions are shown in Fig. 1.2. This regulatory NEM structure is responsible for the overall management of the industry and individual Australian Energy Market Operators (i.e., participating government and privately owned electricity companies). The success of this managerial function and the relevant decision-making process is dependent upon the detailed understanding of the major factors influencing the efficiency and productivity on the Australian electricity market, and upon the development of new effective methodologies evaluating the efficiency and productivity of the individual companies.

About 78% of the energy generated and distributed by the NEM operators (supply chains) is sourced from coal-fired power plants, about 12% by gas-fired plants, about 8% by hydroelectric systems, and about 2.7% by wind generation (Energy Supply Association of Australia, 2011). This energy source mix reflects the available fuel and other energy resources in Australia, as well as the associated generation costs. These figures may significantly vary for different regions, depending on the local regional conditions and availability of energy sources. For example, in South Australia, wind generation constitutes ~ 20% of total installed capacity (Energy Supply Association of Australia, 2011).

## **1.2 Performance and Productivity**

This massive and diverse infrastructure with a large number of different types of public and private operators (supply chains) using a variety of energy sources requires careful management in order to ensure that Australian consumers continue to receive a reliable and secure supply of electricity at a competitive price. This further highlights the need for the development of reliable mathematical and statistical models for the analysis and prediction of performance of individual electricity companies and the industry as a whole. In addition, subsequent to the extensive privatisation, disaggregation and restructure of the electricity generation and distribution industry in Australia, comes the need to understand and evaluate the actual outcomes of these revolutionary restructuring processes aimed at improving industry efficiency, productivity, competition, and consumer orientation.

Productivity is typically defined in close relationship with such other concepts as profitability, economic growth, efficiency, surplus value, quality, performance, etc. (Saari, 2006). At the same time, some economists draw a distinction between the concepts of production efficiency and productivity (Investopedia, 2016):

*“Productivity serves as a measurement of output, normally expressed as a number of units per an amount of time, such as 100 units per hour. Efficiency relates to how well a goal is accomplished, normally by considering the amount of resources used, and waste created, in comparison to goods produced”.*

True productive efficiency is achieved where the economy or firm could not produce any more of one good without sacrificing production of another good.

On the other hand, productivity is also frequently defined as a measurement of the output (produced goods) per unit of input (Saari, 2006):

$$Productivity = \frac{Output\ Quantity}{Input\ Quantity}. \quad (1.1)$$

In this definition of productivity, the distinction between productivity and production efficiency might become rather vague, as the amount of resources used is already taken into account in Eq. (1.1) through the consideration of different inputs. Saari (2006) defined efficiency, in general terms, as a relationship “between producing a *value* and *sacrifices* made in doing so”. This is rather imprecise definition, but it might be considered as capturing the essence of the distinction between the productivity and production efficiency. The concept of ‘sacrifices’ is a rather broad term including, for example, waste created during the production process, as well as other environmental and social losses. Such losses might not be fully accommodated within the concept of ‘Input Quantity’ in Eq. (1.1), which makes a difference between production efficiency and productivity. Nonetheless, a rather conventional and wide-spread approach in the literature and modern theory of production is that production efficiency and productivity are often being used without clear distinction, and productivity is often considered as a specified concept of efficiency (Saari, 2006; Barros, et al, 2008a,b; Jaraitè and Di Maria, 2012; Çelen, 2013; Chen, et al, 2015).

Several mathematical approaches and methodologies have been developed and used for the evaluation of absolute and relative performance, productivity and efficiency of electricity generating and distributing companies and industries. These included the data envelopment analysis (DEA) (Nakano and Managi, 2008; Arocena, 2008; Barros, 2008; Barros, et al, 2008a; Briec et al., 2011; Sueyoshi and Goto, 2011; Jaraitè and Di Maria, 2012; Cook, et al, 2014), stochastic frontier analysis (SFA) (Aigner et al., 1977; Hattori, 2002; Huang et al., 2010; Simar and Zelenyuk, 2011), stochastic non-smooth envelopment of data (StoNED) (Kuosmanen, 2012; Kuosmanen and Kortelainen, 2012; Kuosmanen et al., 2013; Saastamoinen and Kuosmanen, 2016), Bayesian stochastic frontier model (Orea and Kumbhakar, 2004; Greene, 2005; Chen, et al, 2015).

All these methods represented different approaches for the determination of the best performing companies and their rankings in accordance with their levels of productivity and efficiency against the best industry levels of productivity and efficiency. For example, DEA is based on linear programming (constrained optimisation) to determine a production frontier. A production frontier is a line or curve in the input-output mathematical space, corresponding to the best possible practices in a particular industry or a production unit (Battese, 1991). Such best practices are often determined on the basis of historical production data or from other reasonable assumptions (Sena, 2003; Jaraitè and Di Maria, 2012) by means of parametric and non-parametric methods (DEA being one of the non-parametric methods). The production frontier concept may involve deterministic frontiers and stochastic frontiers (Battese, 1991; Prasada Rao, 2016). The major difference between the deterministic and stochastic frontier models is an additional error term present in the stochastic frontier models, causing stochastic frontier fluctuations compared to the deterministic production function (Battese, 1991).

Productivity growth is often determined by means of the Malmquist productivity index (Sena, 2003; Boussemart, et al, 2003; Barros, et al, 2008b) and the Luenberger productivity indicator (Luenberger, 1992; Boussemart, et al, 2003; Barros, et al, 2008b). Several advantages were highlighted for the Luenberger productivity indicator including the possibility of optimising ways for improving productivity of a particular firm to enable it reaching the production frontier (Boussemart, et al, 2003; Barros, et al, 2008b).

The described approaches to the determination of production efficiency, productivity and growth were extensively used in a variety of industries including, amongst others, agricultural production (Battese, 1991), hospital and health services (Barros, et al, 2008b), and power generation and distribution companies (Barros, et al, 2008a; Jaraitè and Di Maria, 2012; Çelen, 2013; Kuosmanen et al., 2013; Oh, 2015; Chen, et al, 2015; Omrani, et al, 2015; Saastamoinen and Kuosmanen, 2016). Productivities of the whole electricity generation and distribution industries and individual firms were examined in cross-sectional and longitudinal studies in a variety of countries and economic environments.

### **1.3 Knowledge Gaps**

The extensive available literature and the big variety of the developed methods for the quantitative evaluation of production efficiency, productivity and their growth demonstrate that this particular research area in econometrics has been extensively developed on the basis of advanced statistical parametric and non-parametric approaches allowing detailed analysis and modelling of productivity issues in modern companies, industries and economies, including in the power generation industry (Barros, et al, 2008a; Jaraitè and Di Maria, 2012; Çelen, 2013; Kuosmanen et al., 2013; Oh, 2015; Chen, et al, 2015; Omrani, et al, 2015; Saastamoinen and Kuosmanen, 2016).



However, the current research efforts in this area have mainly been focused on the reliable determination of productivity levels within industries or companies. Typically, productivity parameters were obtained for a particular industry and/or individual operating units/firms, with no further analysis and/or classification of companies in accordance with their productivity and performance – see, for example, (Battese, 1991; Barros, et al, 2008a,b; Jaraitė and Di Maria, 2012; Çelen, 2013; Kuosmanen et al., 2013; Oh, 2015; Chen, et al, 2015; Omrani, et al, 2015; Saastamoinen and Kuosmanen, 2016). Numerous theoretical papers (referred to in the previous section) focused on the development and improvement of the productivity measurement methods, rather on the analysis and classification of companies in accordance with their productivity, size and other performance parameters. Little attention has been paid to the analysis of the existing trends in company performance as functions of productivity levels, company size, and other parameters. Similarly rather limited research concentrated on optimisation of any such parameters to aid with regulations and policy making in the power generation industries.

For example, the average optimal size of a power generation company in Korea was determined on the basis of a simple linear regression or a robust linear regression of economies of scale versus actual annual generation of electricity output (Oh, 2015). In particular, it was shown that the optimal output for an individual company is around 80 TWh. The average company size (judging by its output) in Korea has been steadily increasing over recent years and is expected to reach the determined optimal output in around 2021 (Oh, 2015). The validity of those outcomes may be limited because of the lack of adjustments to other factors or variables (including labour costs, number of employees, capital assets, etc.) that are capable of impacting on company productivity. This validity concern is particularly supported by the low  $R^2$  coefficient for the considered regressions of about 0.3 (Oh, 2015), which is a strong indication that the analysed trends should have been considered with the

involvement of other variables (including any different company categories) to ensure better model fit. In addition, the outcomes obtained by Oh (2015) may not be applicable to the conditions on the Australian power generation/distribution market.

Further, the massive and diverse infrastructure with a large number of different types of public and private power generating companies in Australia, using a variety of energy sources, requires careful management in order to ensure that the Australian consumers continue to receive a reliable and secure supply of electricity at a competitive price. This is an important and challenging task, particularly taking into account the need for adaptation of the centralised electricity systems to the challenges of rapidly growing peak demand and the growing trend towards fragmented off-grid power supply systems, including solar power generation for individual households (Quezada, et al, 2014). Subsequent to the extensive privatisation, disaggregation, fragmentation and restructure of the electricity generation and distribution industry in Australia, comes the urgent need to identify and evaluate any existing trends in the Australian power generation industry, understand and evaluate the outcomes of those revolutionary processes aimed at improving industry performance, competition, and consumer orientation. The largely uncharted transition from the concept of the ‘natural monopolies’ of public utilities (DiLorenzo, 1996; Joskow, 2007; Perloff, 2012) to market regulations and competition in the power generation and distribution industry requires ongoing reassessment and new methodological approaches suitable for the evaluation of performance and productivity related matters associated with different groups of electricity market operators in Australia.

The associated significant gaps in the existing fundamental and practical knowledge of productivity trends in the new environment of Australian electricity generation and distribution market are particularly related to the lack of consistent analysis of the power generating companies, their statistical classification/categorisation and characterisation in

accordance with their basic performance and productivity parameters. This includes the lack of reliable methods for such characterisation in the Australian (and broader) context. The following important questions have been left largely unanswered:

- Are the existing electricity generating and distributing companies (EGDCs) significantly different from each other and do they require different managerial and/or regulatory approaches?
- How can we classify (categorise) EGDCs to enable better understanding of their management requirements and needs under the condition of significant disaggregation and diversification of the energy market?
- What are the general trends (if any) on the Australian electricity generation/distribution market, including the dynamics of the major performance parameters for EGDCs with mutual performance characteristics?
- Is the currently achieved level of market disaggregation optimal, or it requires further regulatory measures to ensure more efficient industry performance?
- Are there any particularly successful energy operators on the Australian electricity market, whose experience and performance would indicate success or failure of the adopted policies and regulations?

All these unanswered questions represent major obstacles for the development of efficient regulating policies and management approaches by the decision-making bodies in the NEM (Fig. 1.2). Resolution and detailed understanding of these questions will provide additional evidence-based information enabling the regulating and managing bodies to significantly better their support for one of the most important sectors of the Australian economy. The development of the statistical methods for the analysis and classification of EGDCs on the basis of their performance characteristics will further add to the significance

of this project in the Australian and international contexts of power generation and distribution, including the understanding of the next steps to improve policies and business management in this section of Australian economy.

## **1.4 Aims of this Study**

Based on the previous Section 1.3, the general aim of this research is to develop and use comprehensive statistical analysis and modelling to identify and study any distinct groups (categories) of EGDCs on the Australian power generation market, including the identification and analysis of performance trends for these groups and individual companies. Our major goal will thus be to highlight the major characteristics and trends for any reasonable categories of EGDCs in Australia, and to make a showcase for the respective statistical methodology. To achieve this goal, we will adopt the simplest one-input definitions of productivity as the ratio of the power output to labour costs (labour productivity) and power output to company capital assets (capital productivity) – Eq. (1.1). The developed methodologies and their outcomes can be extended to incorporate any other productivity data including that obtained using the DEA and production frontier approaches.

**The specific aims of this study** are as follows:

1. Identification of distinct groups (categories) of electricity supply and/or power generation companies in Australia on the basis of the cluster and principal component analyses of the performance data.
2. Statistical determination and characterisation of the major trends in the company performance data including the capital and labour productivities for different company categories, adjusted to the other variables.

3. Identification and characterisation of the existing paths of causal direct and indirect relationships involving the performance variables for different company categories during the observation period.
4. Case study analysis of representative examples of electricity generation and distribution companies, including their comparison with the findings from the developed statistical models.
5. The comparison and mutual cross-validation of the outcomes and findings resulting from the adopted statistical methodologies.
6. Developing recommendations for the regulating and managing bodies based on the obtained outcomes and findings.

# Chapter 2. Literature Review

## 2.1 Background

There are three major drivers of energy demand, namely, economic activity, population, and technology (Yeager, et al, 2012). The energy needs and access to modern forms of energy largely determine the ‘face’ of the national economy and economic priorities. Electricity is one of the most important and convenient forms of energy, as it is most compatible with the requirements of the modern industries and economic development (Yeager, et al, 2012). It appears to be more than just an energy carrier but also enables all kinds of economic processes from information exchange to production, construction, transportation, and everyday necessities of life. Electricity is an essential tool enabling easy access to energy, technical innovation and productivity growth (Yeager, et al, 2012). Therefore, electric power generation and distribution is at the core of any modern economy. It is hardly possible to imagine any further economic progress without an adequate, reliable and sustainable power supply.

The development of the electric power industries in the developed countries around the world displayed a string of similarities. For example, in the middle of 20<sup>th</sup> century, generation of electric power was widely regarded as a ‘natural monopoly’. As a result, generation and distribution of electric power was heavily regulated by the governments, with only little or no any market competition (DiLorenzo, 1996; Joskow, 2007; Perloff, 2012).

A monopoly is an enterprise that is the only supplier or provider of a particular good or service. According to the theory of natural monopoly, a natural monopoly occurs where “[a]n industry in which multi-firm production is more costly than production by a monopoly” (Baumol, 1977). It is typically regarded that a natural monopoly occurs in an industry with

high infrastructural costs (such as the costs of infrastructure for generation and distribution of electric power), which makes it difficult for new operators to enter the market, and the largest (often, the first) operator has a major advantage over other competitors (Perloff, 2012). Higher prices would result if more than one producer had operated on the market (DiLorenzo, 1996).

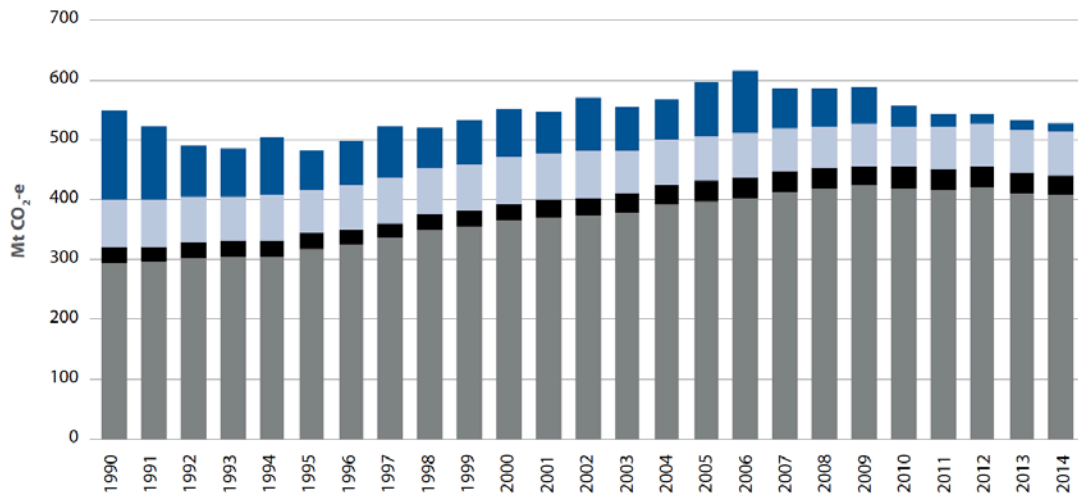
However, there is a certain requirement for regulations of any natural monopolies to ensure they serve public good, but not solely their own corporative needs and interests (Joskow, 2007). This regulatory function largely resided with the respective governments and their bodies. The intrinsic inefficiency of extensive government regulations and interference in any industry, combined with the inability of the ‘natural monopolies’ to effectively and adequately address the rapidly changing economic environments and needs in the modern world, has made it essential to widely introduce deregulations of what was previously perceived as ‘natural monopolies’ (DiLorenzo, 1996). Quite remarkably, similar deregulation processes occurred in the majority of developed economies (including Australia, UK and USA) at the end of 20<sup>th</sup> century. This was a reflection of a general consensus of the majority of mainstream economists that the concept of ‘natural monopoly’ was largely a relic of the past that impeded the effective economic development and market competition within the respective industries and beyond: *“When monopoly did appear, it was solely because of government intervention. ... The theory of natural monopoly is an economic fiction. ... In industry after industry, the natural monopoly concept is finally eroding”* (DiLorenzo, 1996).

These major developments and reforms to eliminate the inefficient ‘natural monopoly’ in the electricity generation and supply industry in Australia included extensive privatisation and deregulation of the power generation and distribution companies. This process was echoed by the similar deregulation efforts in other developed countries including UK and USA. Nevertheless, the lack of prior practical experience with these revolutionary reforms

and deregulation in the power generation sector in Australia (or, in fact, in other countries) created the need for the ongoing monitoring and re-evaluation of the effects of those reforms. This was (and is) necessary to ensure that any outcomes of the undertaken deregulation in the power sector were adequate and served the benefits of the public, deregulated industry, and broader Australian economy. Such monitoring required the evaluation of any productivity and performance trends within the deregulated industry in order to develop useful and effective policies and further government strategies for any regulatory adjustments to the undertaken reform process and/or to further stimulate the development of the power generating sector in Australia.

This is particularly important to ensure adequate and effective adaptation of the centralised electricity systems to the challengers of the rapidly growing and fluctuating peak electricity demand and the growing contribution of the off-grid power supply systems, including solar power generation for individual households (Quezada, et al, 2014). In particular, using the multi-level perspective as an analytical tool, Quezada, et al (2014) showed early signs of potential maladaptation of the electricity system in Australia, including increased grid system costs, increased retail prices, and increased social inequality in relation to the distribution and consumption of electricity. The conducted analysis involved three different levels of factors including: (1) legacy infrastructure, technology, government policies and regulations; (2) new technologies and structures being developed and/or trialed; and (3) external factors such as climatic features, population changes, available resources and economic/social culture. Climatic changes and the delays with an adequate institutional response were named as one of the possible reasons for the observed maladaptation signs (Barnett and O'Neill, 2010; Quezada, et al, 2014).





**Figure 2.1.** Total CO<sub>2</sub>-e (carbon dioxide equivalent) emissions in Mt per year by the indicated major sectors of the Australian economy: ■ land use, land-use change and forestry (e.g., including land clearing and deforestation); ■ agriculture; ■ industrial processes and product use; and ■ energy (including stationary energy plants and transport emissions) (National Inventory Report, 2016).

An appropriate and proportional institutional response to the observed early maladaptation signs in the power generation and distribution industry in Australia also requires the detailed understanding of the intrinsic processes emerging and occurring in this sector of the Australian economy as a result of, and following, the earlier deregulation attempts. The detailed knowledge of such processes and any existing productivity-related trends in power generation and distribution will also be important and useful for facilitating a successful transition of this industry from the reliance on the fossil fuels to new renewable sources of energy. This is also expected to significantly aid with the Australian commitments with regard to mitigation of climate change and global warming (IPCC, 2007).

For example, Fig. 2.1 shows the total CO<sub>2</sub>-e (carbon dioxide equivalent) emissions of greenhouse gases by the four major sectors of the Australian economy (National Inventory Report, 2016). It can be seen that the power sector is increasingly responsible for majority of the CO<sub>2</sub>-e emissions, with more than 400 Mt/year between 2006 and 2014. In addition, the

stationary power sector (which is constituted by stationary power production plants) has been responsible for the increase of CO<sub>2</sub>-e emissions by 79.3 Mt/year over the period of time between 1990 and 2014 (National Inventory Report, 2016). This clearly demonstrates the great importance of the electricity generation industry for any successful attempt to reduce the overall greenhouse emissions in Australia. Knowing and properly understanding of the productivity trends in this industry is expected to facilitate any government regulatory process and/or interventions to enable smooth and successful transition to renewable energy sources with significantly reduced greenhouse emissions (CCC, 2011).

## **2.2 Productivity and Efficiency**

As explained above in the Introduction, the modern concept of productivity and production efficiency is essential for the evaluation and analysis of productivity trends in any industry. Therefore, a significant body of literature has been published over years in relation to the definition and determination of productivity and production efficiency using different mathematical approaches in the context of different industries (Aigner et al., 1977; Hattori, 2002; Orea and Kumbhakar, 2004; Greene, 2005; Nakano and Managi, 2008; Arocena, 2008; Barros, 2008; Barros, et al, 2008a; Huang et al., 2010; Simar and Zelenyuk, 2011; Briec et al., 2011; Sueyoshi and Goto, 2011; Jaraitė and Di Maria, 2012; Kuosmanen, 2012; Kuosmanen and Kortelainen, 2012; Kuosmanen et al., 2013; Cook, et al, 2014; Chen, et al, 2015; Saastamoinen and Kuosmanen, 2016).

### ***2.2.1 Definitions of Productivity and Production Efficiency***

Although productivity is typically defined as a ratio of the amounts of outputs produced as a result of a production process to the amounts of inputs needed to produce these outputs (Eq. (1.1)) (Saari, 2006; Krugman, 2016; Business Dictionary, 2016), its exact

definition could be different depending on the purpose of the productivity measurement and/or data availability (Krugman, 2016). The differences originate primarily from different definitions and/or measurements of the inputs. Different inputs can be used to define productivity, depending on the objectives of the conducted analysis and the available data. For example, if the analysis is focused on the determination of how efficiently an enterprise is using its workforce, labour productivity is typically used, where labour costs or labour time are used as inputs in Eq. (1.1).

Typically, productivity is considered in close relationship with such other production concepts as profitability, economic growth, efficiency, surplus value, quality, performance, etc. (Saari, 2006). In fact, productivity is often regarded as a measure of efficiency of a worker, instrument, enterprise, or production system in converting inputs into the desired outputs (Business Dictionary, 2016). Saari (2006) also closely linked production efficiency and productivity. In particular, he defined production efficiency as a quantitative measure “between producing a *value* and *sacrifices* made in doing so”. This general definition means that the production efficiency could be defined as:

$$Production\ Efficiency = \frac{Output\ Quantity}{Sacrifices\ Made}. \quad (2.1)$$

where *Output Quantity* could be a measure for the amount of the outputs or their market value.

The difference between Eq. (2.1) for production efficiency and Eq. (1.1) for productivity is in the different denominators. *Sacrifices Made* in Eq. (2.1) could mean *Input Quantity* (i.e., ‘sacrifices’ could mean sacrificed or used inputs), in which case, Eqs. (1.1) and (2.1) become indistinguishable. However, *Sacrifices Made* could be regarded as a broader concept than production inputs and could also include, for example, waste produced and any other environmental and social losses associated with the production process (Saari, 2006). In

this case, production efficiency appears to be different (broader and more general than) productivity.

This was, probably, the main reason why some economists and sources make a conceptual distinction between productivity and production efficiency (Investopedia, 2016):

*“Productivity serves as a measurement of output, normally expressed as a number of units per an amount of time, such as 100 units per hour. Efficiency relates to how well a goal is accomplished, normally by considering the amount of resources used, and waste created, in comparison to goods produced”.*

This source (Investopedia, 2016) defines productivity relative to time required for the outputs to be produced, which is a rather narrow definition of productivity, with *Input Quantity* in Eq. (1.1) being regarded as the time spent on production. Although the amount of resources was used by Investopedia (2016) in the related definition of production efficiency (as opposed to other sources typically including resources as *Input Quantity* in the definition of productivity), the presented definition of production efficiency also includes waste created during the production process. This correctly highlights the difference between the concepts of productivity and production efficiency.

Nevertheless, making a conceptual distinction between production efficiency and productivity is not as conventional in the literature on the modern theory of production. A more conventional and wide-spread approach is that productivity is considered as a specified concept of efficiency (Saari, 2006; Barros, et al, 2008a,b; Jaraitė and Di Maria, 2012; Çelen, 2013; Chen, et al, 2015). This approach reflects the widely accepted view that *Input Quantity* in Eq. (1.1) can incorporate any sort of sacrifices made during the production process, and the concept of productivity simply specifies – in a quantitative mathematical form – the production efficiency (particularly in (Saari, 2006)).

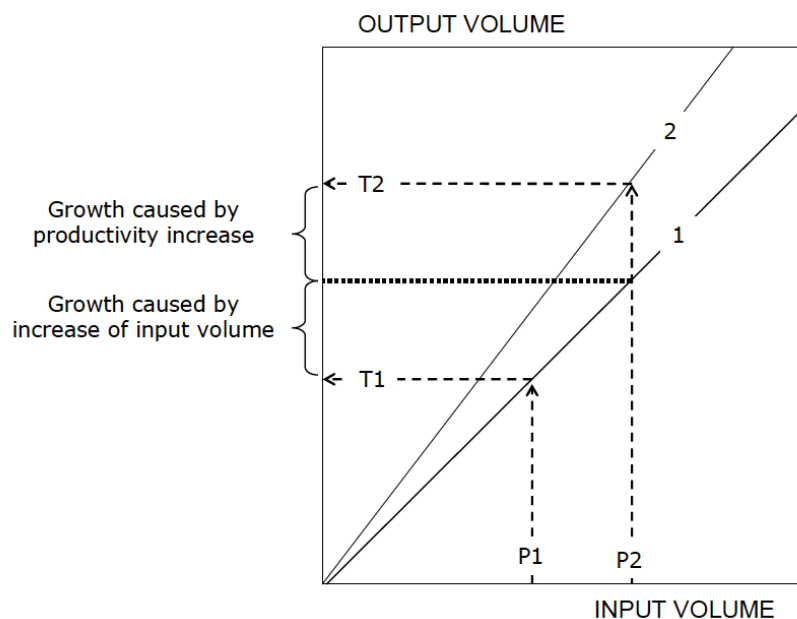
Typically, productivity may be considered in reference to only some selected aspects of the production process and, thus, reflects only partial production trends related to some particular input(s) or resources or production unit, etc. In this case, a notion of partial productivity is introduced (Saari, 2006). Some characteristic examples partial productivity could be (Saari, 2006):

- Single-factor productivity, which considers productivity (Eq. (1.1)) as a function of only one input factor (e.g., labour cost, or capital, or a particular expendable resource, etc.);
- Value-added productivity, in which production output is considered as a value added as a result of the production process;
- Efficiency ratios, which evaluates the produced value (as an output) versus sacrifices made (including possible environmental and/or waste impacts, etc.); or
- Any other meaningful ratios characterising the efficiency and performance of production units or managerial groups, including profitability, quality, market position, etc., or any their combinations.

Partial productivities are typically much simpler to measure and they might offer a better focus on a particular production issue or variable, but they might not provide the overall picture for the production process (Saari, 2006). Nonetheless, partial productivities are an important tool for the analysis, and we will be extensively using this concept in this study, referring to partial productivities as, for example, labour productivity or capital productivity.

### 2.2.2 Determination of Productivity and Production Efficiency

Figure 2 demonstrates the process of productivity and economic growth (Saari, 2006). The horizontal axis corresponds to the production input (*Input Quantity*), and the vertical axis corresponds to the output volume (*Output Quantity*). The two solid lines show the productivity functions 1 and 2 for two different years 1 and 2 (with year 2 occurring after year 1). The production functions mathematically relate production inputs and outputs, and in the considered example the production functions we re assumed to be linear (Fig. 2.2). The years 1 and 2 correspond to the two different levels of production inputs (*Input Quantities*)  $P_1$  and  $P_2$  that produce the two outputs  $T_1$  and  $T_2$ , respectively (Fig. 2.2).



**Figure 2.2.** Graphic illustration of productivity and economic growth (Saari, 2006).

As can be seen from Fig. 2.2., production growth is often associated with the two different production aspects: (1) growth caused merely because of the increase of the Input Quantity (from  $P_1$  in year 1 to  $P_2$  in year 2); and (2) growth due to the increase of productivity. Growth due to productivity increase corresponds to a transition from the production curve 1 to the production curve 2 (Fig. 2.2). This means that productivity has

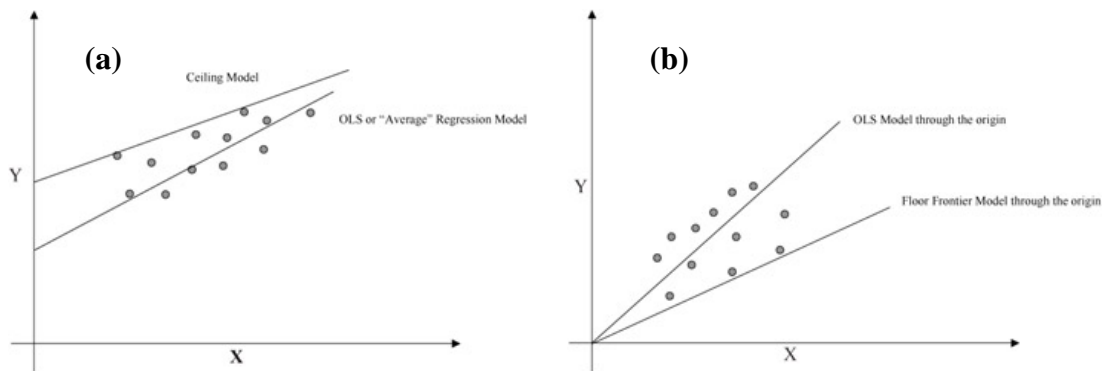
increased from year 1 to year 2, which is shown by a new production function with a larger slope corresponding to larger output for a given input (the ratio between the output and input in Eq. (1.1) gives the slope of the production function).

One of the widely adopted statistical approaches for the analysis of productivity trends and efficiency of a particular enterprise or company is based on the comparison of the company in question with other companies and the best available practices in the industry the considered company belongs to. This approach enables the determination of the productivity benchmark for each particular industry (Troutt, et al, 2001; Sena, 2003; Kuosmanen, et al, 2013) and the respective targets for each particular company in the form of the directional distance function or the Luenberger indicator – both representing the shortest quantitative ‘distance’ between the company and the best practice frontier (Barros, et al, 2008b).

A production frontier is a line or curve determining a relationship between production inputs (as the independent variables) and outputs (as the dependent variables), corresponding to the best possible practices in a particular industry or a production unit (Battese, 1991; Troutt, et al, 2001; Sena, 2003). The best practice frontier can be determined using different methods including, in some cases, the historic data relevant to a particular industry/company (Jaraitė and Di Maria, 2012).

A mathematical methodology enabling the determination of a best practice frontier can be based on the so-called frontier regression (Troutt, et al, 2001). An ordinary regression that seeks to explain data variations on the basis of the average behaviour that can be seen from the available data trends. Contrary to this, a frontier regression model seeks to determine and describe the behaviour of the data at an observational boundary, which may include optimal or best possible behaviour (Troutt, et al, 2001). Put differently, the frontier analysis approach could be used for simulating the input-output functional relationships in the presence of theoretical bounds (Prasada, 2016).

There are two different types of frontier regressions – ceiling frontier regression and floor frontier regression (Troutt, et al, 2001). The ceiling frontier model describes the topmost performers on the basis of the available data, while the floor frontier model describes the bottommost performance and trends. Fig. 2.3 shows the examples of the ceiling and floor frontier models in comparison with the ordinary (conventional) linear regression models on two sets of hypothetical data. As illustrated by Fig. 2.3, the ceiling and floor frontier regression models present the upper and lower limits for the dependences of the Y variable versus the X variable.



**Figure 2.3.** Illustrations for: (a) the ceiling; and (b) the floor frontier models (Troutt, et al, 2001). Both sub-plots show the lines corresponding to the ordinary linear regression models for both the datasets, which are presented for comparison with the two frontier models.

In the theory of production and productivity, we are typically interested in the determination of the best possible performance within some particular industry or company. As a result, the modern production theory typically considers the ceiling frontier models (further below termed simply as ‘frontier models’ or ‘production frontier’) to evaluate productivity and efficiency of companies and firms, their productivity growth and comparison with the best practice performance in the industry.

Evaluation of the benchmark performance given by a production frontier can be achieved using different mathematical approaches including the principle of maximum

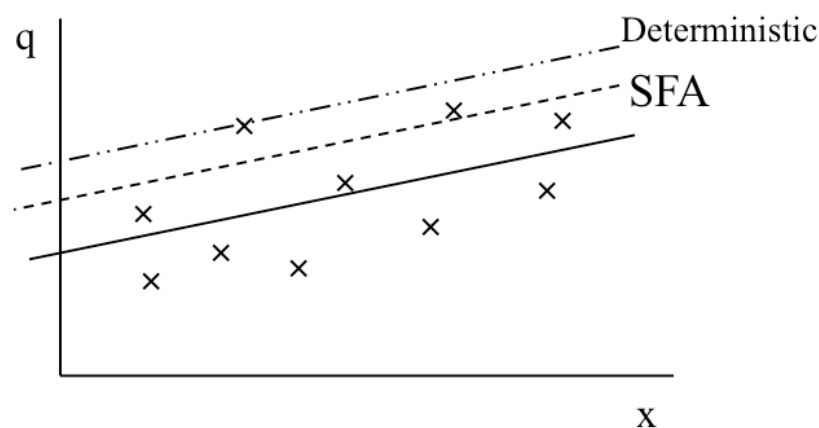


performance efficiency (Troutt, et al, 2001, 2003), directional distance function (Barros, 2008; Barros, et al, 2008a,b), data envelopment approach (DEA) (Nakano and Managi, 2008; Arocena, 2008; Briec et al., 2011; Sueyoshi and Goto, 2011; Jaraitė and Di Maria, 2012; Cook, et al, 2014), or stochastic non-smooth envelopment of data (StoNED) (Kuosmanen, 2012; Kuosmanen and Kortelainen, 2012; Kuosmanen et al., 2013; Saastamoinen and Kuosmanen, 2016), or Bayesian stochastic approach (Orea and Kumbhakar, 2004; Greene, 2005; Chen, et al, 2015). The frontier evaluation is often conducted using linear programming, i.e., optimisation under constraints (Troutt, et al, 2001, 2003; Sena, 2003; Barros, et al, 2008b; Jaraitė and Di Maria, 2012).

In fact, DEA is one of such linear programming approaches applicable to a wide range of productivity and performance data (Sena, 2003; Nakano and Managi, 2008; Arocena, 2008; Briec et al., 2011; Sueyoshi and Goto, 2011; Jaraitė and Di Maria, 2012; Cook, et al, 2014). In addition, DEA is a non-parametric method for the estimation of the best practice frontier, which does not need to assume any particular knowledge or expectation of the structure of the observational data or functional form of technology (Sena, 2003; Jaraitė and Di Maria, 2012). This is a significant advantage for industry level data, given the diversity of the companies, production systems, resources, and environmental and/or business conditions (Jaraitė and Di Maria, 2012).

Parametric methods for the estimation of the best practice frontier also exist, using econometrics to evaluate the frontier (Sena, 2003), including the one based on the principle of maximum performance efficiency (Troutt, et al, 2001, 2003). However, parametric methods have significant disadvantages due to their reliance on a functional form for the production function (technology) and assumption of a particular distribution of the distance between the company performance and the best practice frontier (also termed as ‘inefficiency’) (Sena, 2003).

The non-parametric approaches to the best practice frontier were often linked to the determination of different measures of productivity and productivity growth/trends, including the Malmquist productivity index (Sena, 2003; Boussemart, et al, 2003; Barros, et al, 2008b) and the Luenberger productivity indicator (or the directional distance function that is opposite to the Luenberger productivity indicator) (Luenberger, 1992; Boussemart, et al, 2003; Barros, et al, 2008a,b; Briec et al., 2011).



**Figure 2.4.** Production functions/frontiers for the input  $x$  and output  $q$  (Prasada Rao, 2016): ordinary linear regression (OLR) (solid line); SFA (dashed line); deterministic frontier (dash-and-dot line).

The frontier methods were sub-divided into two different classes of models – stochastic frontier analysis (SFA) and deterministic (or pure) frontier models (Battese, 1991; Truett, et al, 2001). The major difference between these two classes of frontier models is that SFA assumes an additional error term that causes stochastic frontier fluctuations compared to the deterministic production function (Battese, 1991). These fluctuations take into account ‘favourable’ or ‘unfavourable’ production conditions for which the additional error term is positive or negative, respectively, causing fluctuations of the best possible production practices under the given conditions.

The differences between the ordinary (least square) regression model, the deterministic frontier model, and the stochastic frontier model are illustrated by Fig. 2.4 showing these three statistical models for a hypothetical set of data shown by crosses, and by the following defining equations (Prasada Rao, 2016):

$$\begin{aligned}
 \text{OLR:} \quad & \mathbf{q}_i = \beta_0 + \beta_1 \mathbf{x}_i + \mathbf{v}_i; \\
 \text{Deterministic:} \quad & \mathbf{q}_i = \beta_0 + \beta_1 \mathbf{x}_i - \mathbf{u}_i; \\
 \text{SFA:} \quad & \mathbf{q}_i = \beta_0 + \beta_1 \mathbf{x}_i - \mathbf{u}_i + \mathbf{v}_i,
 \end{aligned} \tag{2.2}$$

where  $\mathbf{q}_i$  and  $\mathbf{x}_i$  are the production outputs and inputs (there is a possibility of multiple inputs and outputs, which is why they are shown as vectors);  $\mathbf{v}_i$  is the ‘white noise’ error term reflecting the natural (e.g., normal) distribution of the production outputs depending on a variety of production conditions; and  $\mathbf{u}_i$  is the inefficiency error term quantifying the ‘distance’ between a particular company efficiency and the best industry practices ( $\mathbf{u}_i$  cannot be negative, illustrating that company efficiency cannot exceed the best industry practices). Eqs. (2.2) determine the respective fitting lines in Fig. 2.4.

In particular, it follows from Eqs. (2.2) and Fig. 2.4 that while the performance of any particular company cannot exceed the level of performance corresponding to the deterministic frontier (dash-and-dot line in Fig. 2.4), level of performance of some companies can exceed the stochastic frontier (dashed line in Fig. 2.4). This can happen because of the presence of the white noise error term  $\mathbf{v}_i$ . Figure 2.4 also further demonstrates that, whereas the frontier models determine the (deterministic or stochastic) boundaries of company efficiency and productivity (i.e., optimal performance), the ordinary linear regressions/models explain the average behaviour. Understanding of this difference is important for this study because it is largely based on ordinary linear regressions to establish

and compare industry-average behaviour and productivity trends for the identified categories of company groups.

### ***2.2.3 Critical Evaluation of Research in Productivity in Power Industries***

The described methods for the analysis of productivity and productivity growth have been used for the evaluation of performance in a variety of industries including, amongst others, agricultural industry (Battese, 1991), medical and hospital services (Barros, et al, 2008b), and power generation and distribution companies (Barros, et al, 2008a; Jaraitė and Di Maria, 2012; Çelen, 2013; Kuosmanen et al., 2013; Oh, 2015; Chen, et al, 2015; Omrani, et al, 2015; Saastamoinen and Kuosmanen, 2016). Productivities of the whole electricity generation and distribution industries and individual firms were examined in cross-sectional and longitudinal studies in a variety of economic environments and countries including European Union (Jaraitė and Di Maria, 2012), Finland (Kuosmanen, 2012; Kuosmanen et al., 2013), Portugal (Barros, 2008; Barros, et al, 2008a,b; Briec et al., 2011), Turkey (Çelen, 2013), Korea (Heshmati, et al, 2012; Oh, 2015), Taiwan (Chang, et al, 2009; Liu, et al, 2010), China (Chen, et al, 2015), Iran (Omrani, et al, 2015), Japan (Sueyoshi and Goto, 2011), USA (Sueyoshi, et al, 2010), etc.

There have been numerous attempts to evaluate and compare the production efficiency and productivity in the power generation and distribution industry for different types of generating plants including, for example, nuclear and fossil fuel-based generation plants (Kamerschen and Thompson, 1993), older and newer plants with different types of fuels (Chang, et al, 2009), coal and gas powered thermal electricity generation plants (Hiebert, 2002), hydroelectric power generating plants (Barros, 2008; Barros, et al, 2008a; Briec, et al, 2011), and relative efficiency of thermal electricity generation plants under the impacts of environmental factors and policy restrictions (Fare, et al, 1986; Sueyoshi, et al,

2010). On several occasions, power generating companies and plants with different types of fuels were considered as separate groups enabling the separate analysis of any associated productivity and efficiency trends (Hiebert, 2002).

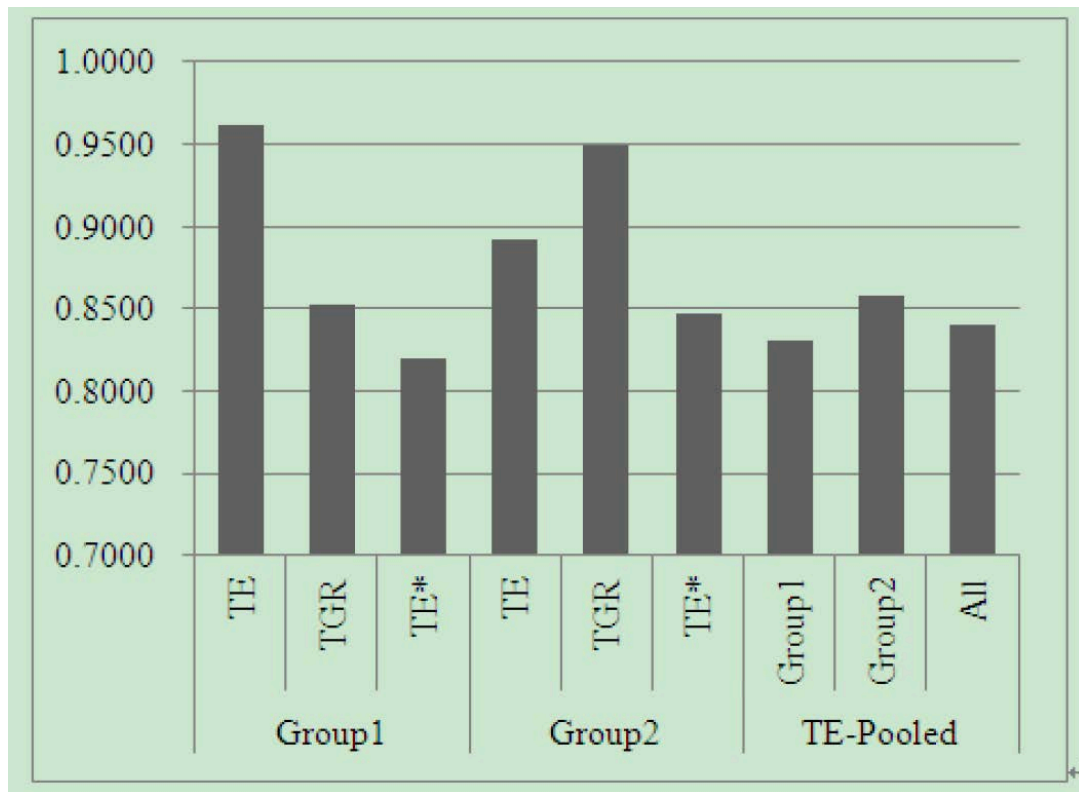
Heshmati, et al (2012) suggested that the consideration of power generation plants with different fuel types and generating technologies “*has inevitable limitations in comprehending the overall performance of industry*”. However, this statement might not be fully accurate and demonstrates some potential deficiencies in the productivity analysis conducted so far. This is because properly designed statistical models do not necessarily require separation of different objects/observations into separate homogeneous groups to ensure reliable statistical outcomes. Quite to the contrary, simultaneous consideration and productivity modelling of different types of power plants could be of a significant benefit, as this will increase the considered sample size (which could often be rather limited, particularly for smaller countries and markets). The statistical models involving categorical variables (e.g., reflecting different types of fuels or other distinct characteristics of the considered power generating companies), as well as the incorporation of the mixed effects modelling, should enable reliable and consistent analysis of the existing productivity trends in a heterogeneous power generation industry. Because of the positive impact of an increased overall sample size, the analysis outcomes should often be more reliable and statistical significant for a larger heterogeneous sample, than for the significantly smaller homogeneous sub-samples (Cohen, 1988; Aberson, 2010).

One of the proposed solutions to the heterogeneity problem was the development of the metafrontier models (Battese and Rao, 2002; Battese, et al, 2004; O'Donnell, et al, 2008; Kounetas, et al, 2009). These models enabled the analysis and comparison between production units with different technologies (e.g., generation plants with different types of fuels) and/or under different environmental and production conditions. They considered

production frontiers at two different levels – for the same technology groups (level 1) and for the whole heterogeneous sample (level 2). Differences between the homogeneous groups of companies and between companies within each of the groups could be determined and analysed in this case. Initially, the main focus was on variations between different regions and/or regions, but later this methodology was also extended to involve technological differences between companies within a particular industry sector of fossil-fuelled power plants (Heshmati, et al, 2012). In this study, the outputs and inputs of the considered companies/plants were the same, but they used different production processes (technologies).

Despite the development of the metafrontier models for heterogeneous samples of companies, Heshmati, et al (2012) still indicated: “*there is an on-going debate on the problem of comparison between heterogeneous plants*”. This suggests that there is still a lack of general consensus as to the methodological approaches to the productivity analysis of significantly heterogeneous samples of power generating and distributing companies. This also illustrates the need for the development of any alternative methodologies and/or approaches applicable for the productivity analysis in the heterogeneous context of the national power generation markets (which was one of the significant motivations for the current study – see Section 1.4 above).

Although the proposed classification of power generating companies in accordance with fuel types was rather intuitive, it still needs mathematical corroboration and justification. Further, there could be other parameters and factors (possibly, not as intuitive as fuel type) that might also need to be taken into account when constructing reasonable classification (categorisation) of EGDCs. This justifies the need for statistical methodologies allowing classification of such companies on the Australian market, which would have ensured an adequate determination and analysis of any productivity trends after the undertaken deregulation of the industry.



**Figure 2.5.** The outcomes of the metafrontier analysis of the thermal power generating plants in Korea with the two distinct groups: steam turbine plants (Group 1) and combined cycle power plants (Group 2) (Heshmati, et al, 2012). The inter-group difference is expressed by the technology gap ratio (TGR); the intra-group difference is expressed by the technical efficiency given by the level 1 frontiers for the two considered groups (TE); TE\* is the technical efficiency for each group obtained from the level 2 frontier.

Heshmati, et al (2012) proposed the two distinct groups of power plants in Korea (separated by generation technology) for the metafrontier model – steam turbine plants (Group 1) and combined cycle power plants (Group 2). The conducted metafrontier analysis demonstrated significant differences between the efficiency trends within the considered groups (Fig. 2.5). Although the selection of the two considered groups adopted by Heshmati, et al (2012) appeared intuitive (and resulted in different characteristic outcomes – Fig. 2.5), there was no mathematical proof of validity of this subdivision. Further, the conducted analysis was developed for different power generating plants but not for generating

companies, whereas the company analysis could be seen as more interesting for the Australian post-deregulation conditions (to determine performance of different companies each of which could be operating several different plants or facilities). The outcomes were specific to Korea and might not be applicable to the Australian electricity market, particularly when taking into account the significant differences in territorial size of the market (significantly larger for Australia) and significantly larger population in Korea (about 50 million), compared to about 23 million in Australia.

Similarly, the analysis conducted by other researchers, for example, for Portugal (Barros, 2008; Barros, et al, 2008a,b; Briec et al., 2011), may also be inapplicable to Australian conditions because of the significant territorial and population differences. At the same time, the small population market may result in limited economies of scale, which might have an impact on productivity trends (Barros, et al, 2008a). This issue might also be relevant to Australia having relatively small population (while being dispersed over very large territory – Fig. 1.1).

In addition, most of the developed productivity models and literature sources listed above focused on the accurate determination of the production frontiers (industry best practices) and the subsequent comparison of individual companies/plants with these best practices. The majority of these models were dealing with cross-sectional studies and did not provide sufficient information about productivity trends and changes over time (while understanding of such trends would be particularly important for the evaluation of the performance of individual operators on the Australian power generation/distribution market after the undertaken industry deregulation). The frontier-based models are important and useful models as they allow the identification of underperforming companies and likely ways to improve their performance and close the gap with the best industry practices given by the frontiers. At the same time, as indicated above, the production frontier models do not

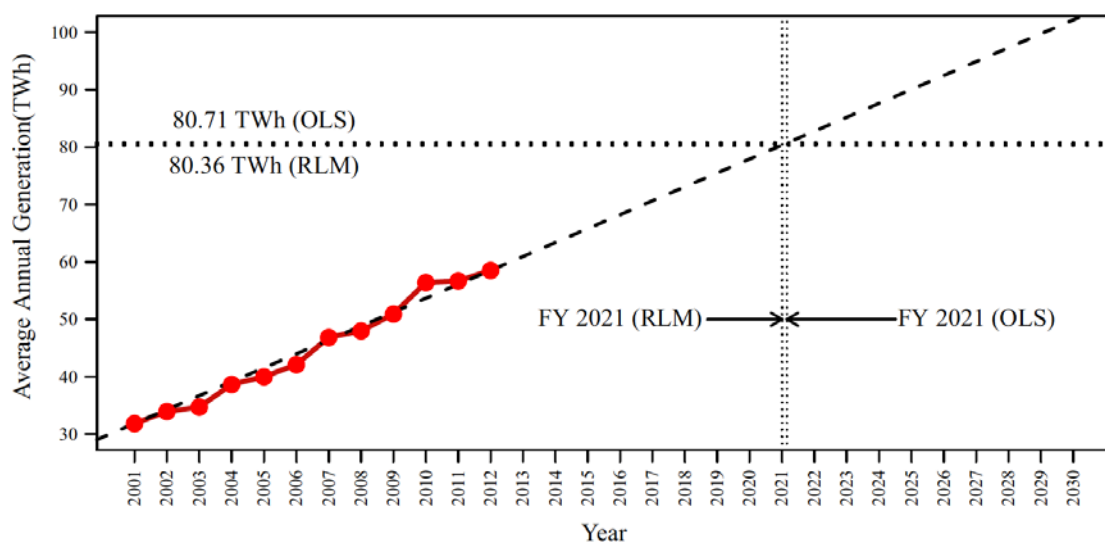


normally provide a tool for a justified mathematical classification (categorisation) of different power generating and distributing companies. In addition, they do not determine direct and indirect impacts of different factors and parameters on the productivity trends and do not normally offer opportunities to characterise the dynamics or evolution of such trends in time.

Therefore, this study attempted to overcome the indicated shortcomings of the previous analysis and methodology through the development and application of new statistical approaches to determine and analyse average productivity trends in the Australian power generation and distribution industry. The analysis and characterisation of average productivity trends in the industry was deemed important for the overall understanding and assessment of the outcomes of the attempted market deregulation. Therefore, the frontier models were not used in the conducted analysis, but the research efforts were rather focused on identification of any possible clustering of the Australian electricity generating and/or distributing companies (EGDCs), and determination of networks of direct and indirect effects of different company characteristics on its average productivity and productivity trends under the Australian power market conditions subsequent its deregulation process. The general and specific aims of this study were formulated above in Section 1.4.

One of the important aspects of the analysis of EGDCs or any their reasonable groups is the prediction of their optimum size or characterisation of the productivity trends as a function of company size. This would enable recommendations to the relevant government bodies and regulating authorities, facilitating decision making and policy development to ensure optimised market performance. Only few attempts to determine optimum average company size have been undertaken so far. For example, Oh (2015) determined the average optimum power output for an individual company within the Korean power generation market. In this paper, company size was defined as the power output produced by this company. Although this is one of the possible ways to define company size, there are other

options for such a definition, which could be more useful and more characteristic of the actual size of the company. For example, company size could be measured by the total number of employees, or by the overall employee costs, or by the total assets owned by the company in the form of Property, Plant & Equipment (PP&E). To the best of our knowledge, productivity trends have not been properly analysed as a function of any of these parameters representing company size, and particularly in the case of several such parameters considered in the same statistical model.

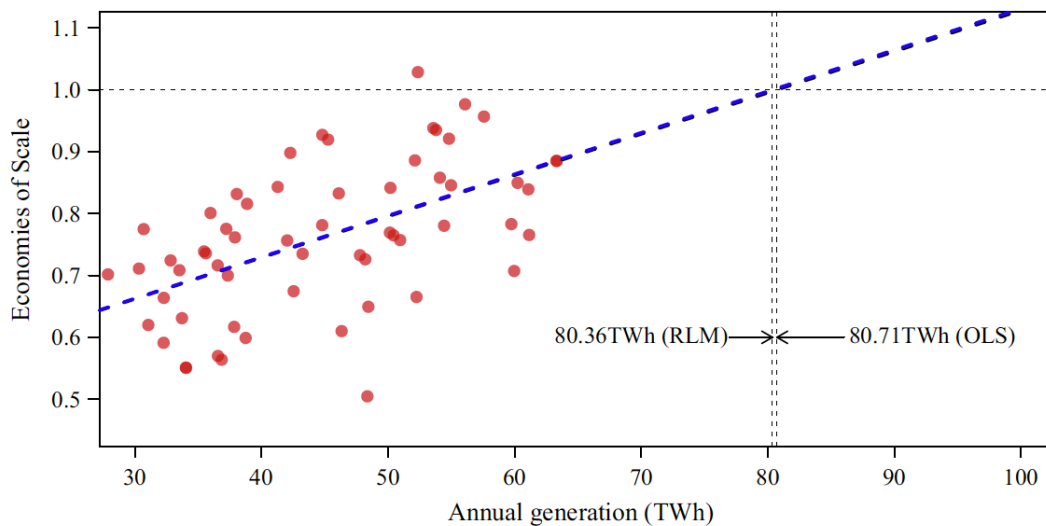


**Figure 2.6.** The average actual (red dots) size of a fossil-fuel generation company in Korea as a function of time (Oh, 2015). The optimum size of an individual company is indicated by the horizontal dotted line (the company size was determined as its total power output – about 80 TWh) and is expected to be reached by around 2021.

Further, the analysis conducted by Oh (2015) was conducted on the basis of simple regressions – either the robust linear regression model (RLM) or the ordinary least squares (OLS) linear regression model. It is quite clear that these regression models poorly explained the considered data, which is highlighted by the large spread of the experimental observations around the plot for economies of scale (Fig. 2.7) and the corresponding small  $R^2$  coefficients

(of around 30%). This is a strong indication that the conducted predictions were rather unreliable because of the following two significant methodological shortcomings:

1. The analysis was only based on a simple regression model (RLM or OLS) with only one independent variable – annual generation output (Fig. 2.7). Clearly other factors/variables have caused the significant dispersion of the observation points (red dots in Fig. 2.7) around the regression line, resulting in the low  $R^2$  coefficients. To remove or alleviate this difficulty, multiple linear regressions including other significant factors/variables relevant to the company output and economies of scale must be used instead.
2. The analysis was conducted for several different fossil-fuel power generating companies. This requires the use of mixed (or random) effects modelling, but it was not used by Oh (2015) to predict the optimum company size.



**Figure 2.7.** The scatter plot of economies of scale versus total company power output per year (Oh, 2015). The two regression lines resulting from the robust linear regression model (RLM) or the ordinary least squares (OLS) linear regression model are shown by just one dashed line because of their extreme closeness to each other.

In addition, the size optimisation analysis by Oh (2015) was conducted under the Korean conditions, which might not be applicable to the Australian conditions (and this will be confirmed below by this study). Therefore, these shortcomings and limitations of the analysis conducted by Oh (2015) served as further motivations for the more detailed and comprehensive analysis under the Australian conditions, based on multiple regressions with mixed effects and generalised structural equation modelling, including any dependences of productivity trends on time and company size.

## 2.3 Supply Chains

It has been widely recognised in the literature that power distribution is achieved in the modern economy infrastructure requires involvement of supply chains (SCs). Similar to productivity, SCs could be defined somewhat differently, depending on the specific context used or needed. For example:

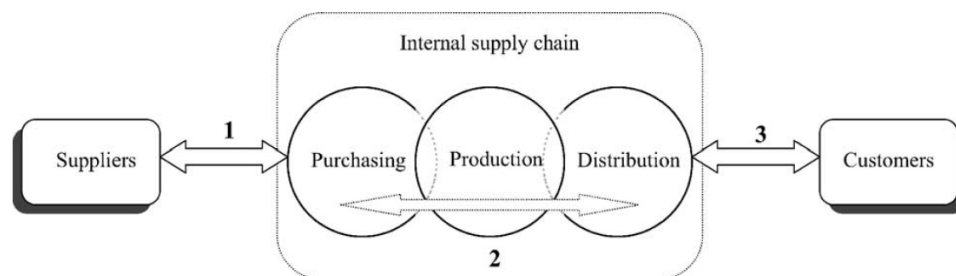
*“A supply chain is a network between a company and its suppliers to produce and distribute a specific product, and the supply chain represents the steps it takes to get the product or service to the customer”* (Investopedia, 2016b);

*“Definitions of a ‘supply chain’ virtually universally encompass the following three functions: (i) supply of materials to a manufacturer; (ii) the manufacturing process; and (iii) the distribution of finished goods through a network of distributors and retailers to a final customer. Companies involved in various stages of this process are linked to each other through a supply chain”* (Canadian Supply Chain Sector Council, 2016);

*“Entire network of entities, directly or indirectly interlinked and interdependent in serving the same consumer or customer”* (BusinessDictionary, 2016).

There has been a significant body of literature on modelling, characterisation and management of SCs (Ganeshan and Harrison, 1995; Harland, 1996; Lambert, et al, 1998; Christopher 1998; Lummus and Vokurka, 1999; Lambert and Cooper, 2000; Min and Zhou, 2002; Harland, et al, 2003; Flint, 2004; Chen and Paulraj, 2004a,b; Collin and Rousell, 2003; Lambert, 2008; Weiss and Kelly, 2008; Shah, 2009; Kim, 2009; Sunil, 2011; Hassini, et al, 2012; Wee, et al, 2012; Näslund and Hulthen, 2012; Mulhall and Bryson, 2014; Mansson et al., 2014; Bustamante and Gaustad, 2014; Cecere, 2014). The literature sources on supply chains span a wide range of industry sectors including agriculture, automotive industry, education, electric power supply, retail, healthcare, housing and construction, mining, transportation and utilities (Hassini, et al, 2012).

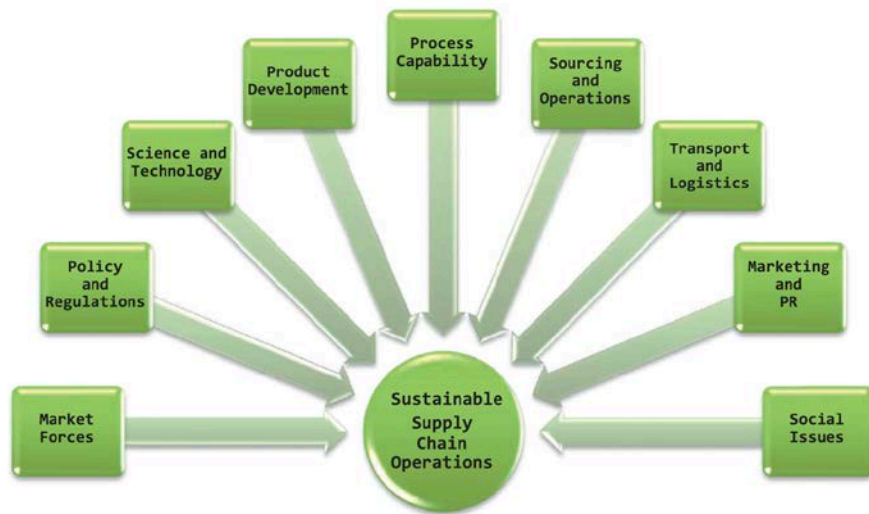
Figure 2.8 shows the typical scheme for a SC involving the suppliers and customers (Chen and Paulraj, 2004). The arrows indicate the mutual impacts of the presented elements of SC on each other.



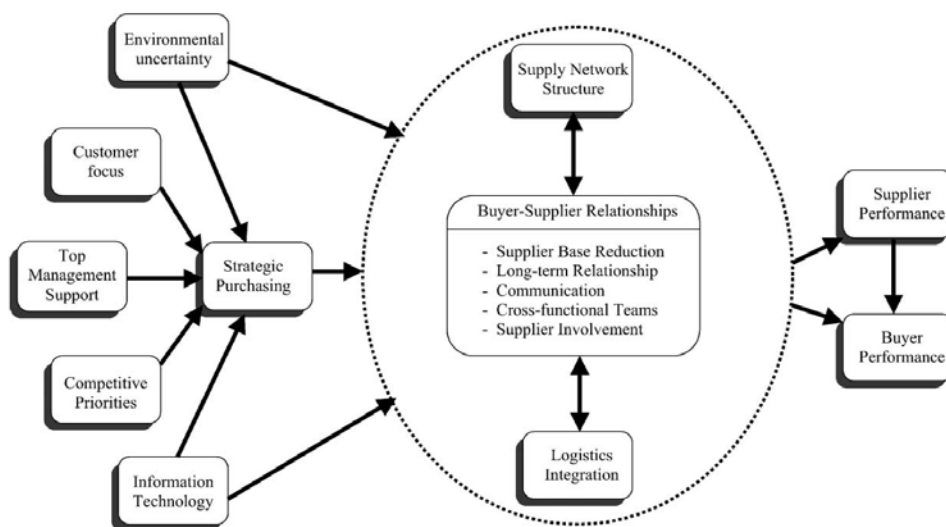
**Figure 2.8.** An illustration of a typical SC as a network comprised of the suppliers, production process and customers (Chen and Paulraj, 2004).

Significant research efforts have been focused on identification and impacts of SCs on the environment, including the sustainability of SCs (Hassini, et al, 2012 and references therein). The considered sustainability issues are particularly relevant to SCs in the power generation and distribution industry, as the power sector in the developed and developing economies (including in Australia) is the major single contributor to the industrial greenhouse

gas emissions (National Inventory Report, 2016) (see also Fig. 2.1) and the related environmental issues and climate change (IPCC, 2007).



**Figure 2.9.** Factors influencing performance of a sustainable (or any other) supply chain (Hassini, et al, 2012).



**Figure 2.10.** The conceptual framework of SC management showing the major constructs impacting on each other and SC performance (Chen and Paulraj, 2004)

Some of the main factors having impacts on the performance of supply chains (sustainable or any other) are shown in Fig. 2.9 (Hassini, et al, 2012), and the major research

framework for supply chain management is illustrated by Fig. 2.10 (Chen and Paulraj, 2004).

Below is the brief outline of the constructs included in the conceptual framework shown in Fig. 2.10 (Chen and Paulraj (2004):

Environmental uncertainty:

- Supply uncertainty: aspects related to quality, timely supply, and any inspection requirements for the supplied materials/goods;
- Demand uncertainty: fluctuations and variations in demand;
- Technology uncertainty: emerging technological changes in the industry.

Customer focus:

- This construct constitutes the intention and strategies of a company/organisation/SC to address any customer needs or expectations, and it includes execution of strategic planning, quality initiatives, product customisation, and responsiveness to any associated stimuli (Ahire et al., 1996; Carson et al., 1998; Tan et al., 1999; Collin, et al, 2009).

Top management support:

- This construct is characterised by the time and resources contributed by the top management to strategic purchase decisions, supplier relationship development, and adoption of advanced information technology.

Competitive priorities:

- SC aspects associated with cost, quality, flexibility, innovation, speed, time and dependability (Corbett and Van Wassenhove, 1993; Miller and Roth, 1994; Kathuria, 2000; Santos, 2000).

#### Strategic purchasing:

- A fundamental function of SCM (Gadde and Hakansson, 1994; Fung, 1999), and it is based on proactive and long-term focuses and successful strategically managed supplier relationships (Reck and Long, 1988; Carter and Narasimhan, 1993; Van Weele and Rozemeijer, 1996; Carr and Smeltzer, 1997, 1999).

#### Information technology:

- This construct includes electronic transactions and communication (Greis and Kasarda, 1997; Carr and Pearson, 1999) and access to information and data regarding aspects of product availability, inventory level, shipment status, production requirements and control, consumer behaviour, advertising, etc. (Radstaak and Ketelaar, 1998).

#### Supply network structure:

- This construct refers to a firm or a group of firms, their suppliers and customers, and their relationships with SC and with each other, including inter-firm coordination and informal social systems (Alter and Hage, 1993; Harland, 1996; Jones et al., 1997; Stock et al., 2000; Lambert and Cooper, 2000; Croom, 2001).

#### Buyer-supplier relationships:

- Supply base including indications of limited suppliers, contractual agreements and supplier retention policies (Kekre et al., 1995; Shin et al., 2000).
- Long-term relationships: selection and integration of a supplier into SC with a lasting effect on the competitiveness and SC performance (Choi and Hartley,



1996; Moore, 1998; Shin et al., 2000; Fynes and Voss, 2002; Kotabe et al., 2003; Sahay, 2003).

- Communication between the supplier and the buyer (Hahn et al., 1990; Morgan and Zimmerman, 1990; Carr and Pearson, 1999; Carr and Smeltzer, 1999).
- Cross-functional teams of industry professionals significantly adding to the proficiency, efficiency, and profitability of SC (Hahn et al., 1990; Narus and Anderson, 1995; Helfert and Gemunden, 1998; Santos, 2000):
- Supplier involvement in, and impact on, the production process and its outcomes (Burton, 1988; Shin et al., 2000; Primo and Amundson, 2002; Ragatz et al., 1997, 2002).

#### Logistics integration:

- Ensures the availability of products at the right time and place, and involves integration of the logistics function of the SC partners (Stock et al., 2000).

#### Supplier performance:

- Includes quality, cost, flexibility, adherence to delivery schedules and response time (Tan et al., 1998, 1999; Jayaram et al., 1999; Kathuria, 2000; Shin et al., 2000).

#### Buyer performance:

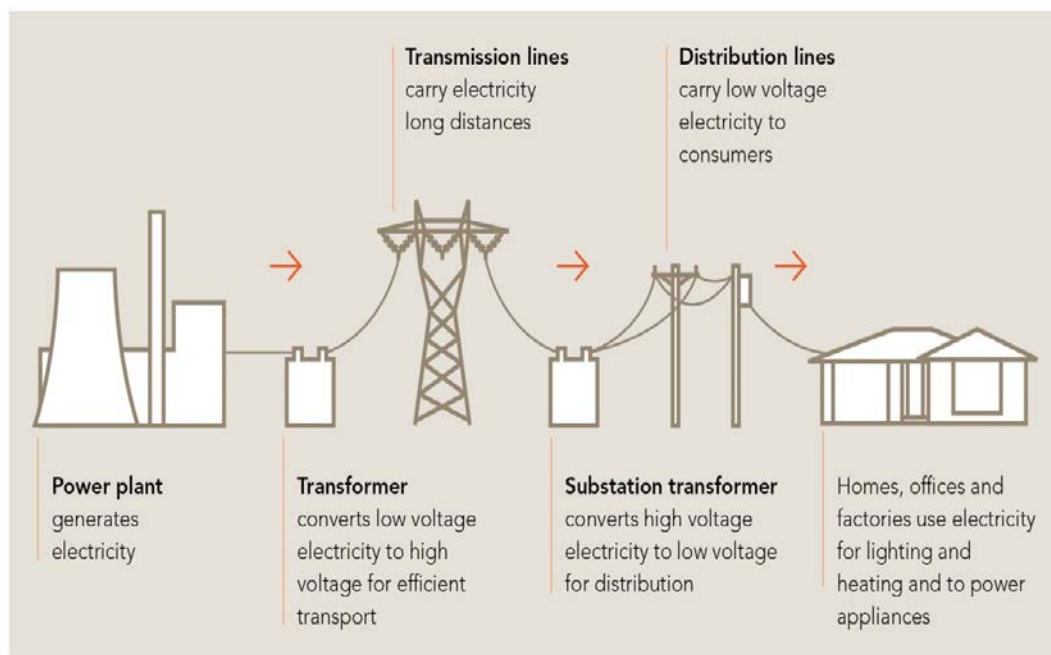
- Includes operational and financial performance, likelihood of returns on investment, accrued profit, present value and net annual income (Beamon, 1999; Jayaram et al., 1999; Neely, 1999; Kathuria, 2000; Medori and Steeple, 2000; Cambra-Fierro and Polo-Redondo, 2008).

A four-page questionnaire was developed and validated by Chen and Paulraj (2004) to represent a measurement instrument for the evaluation and validation of these proposed constructs in the context of SC management. The exploratory and confirmatory factor analyses, as well as other statistical validating criteria including the Cronbach's alpha analysis, were used to construct and validate and quantitatively determine the factors (constructs) in accordance with the proposed framework (Fig. 2.10). Unfortunately, Chen and Paulraj (2004) have stopped short of developing a comprehensive statistical model that would have determined a network of direct and indirect impacts of their constructs on each other and on SC performance. This was a significant shortcoming of this paper that largely limiting its consideration to just exploratory statistical methodologies and leaving aside any predictive tools. As a result, the obtained outcomes (Chen and Paulraj, 2004) did not allow any predictions of productivity trends or quantitative comparison between the impacts of different identified factors on SC performance.

In the emerging inter-network competitive environment, the ultimate success of a single business depends on its management's ability to integrate into the larger SC involving this business. Therefore, the scope of SC management has widened from intra-organisational to inter-organisational focuses and relationships (Dubois, Hulthen and Pedersen, 2004). In this sense, SC has a significant impact on the performance and productivity of each individual business or production unit involved in the SC (Kim, 2009). Similarly, because SC is constructed of individual businesses closely cooperating with each other to produce and deliver the desired outcome or product, performance and productivity of each individual production unit will have an impact on the performance and productivity of the whole SC. From this point of view, the involvement of a particular company in a SC, or that a particular company has significant structural elements of SC, are important factors for the company productivity and any its trends.

## 2.4 Electricity Supply Chains and EGDCs

Importantly, many companies producing and distributing electric power to a customer network have significant structural elements of supply chains linking suppliers, energy producers, distributors, and customers (Nagurney and Matsypura, 2004; Liu and Nagurney, 2009; Et-Tolba and Afia, 2010; Wang and Cong, 2012; Hoggett, 2013). The main components of SC within the power sector include power generation, electricity transmission, distribution, electricity storage, communications, service location and IT solutions (Johansson and Burnham, 1993; Dacruz and Martin, 2011).



TRANSPORT OF ELECTRICITY

**Figure 2.11.** The major components of the electricity SC (Energy Efficient Exchange, 2015).

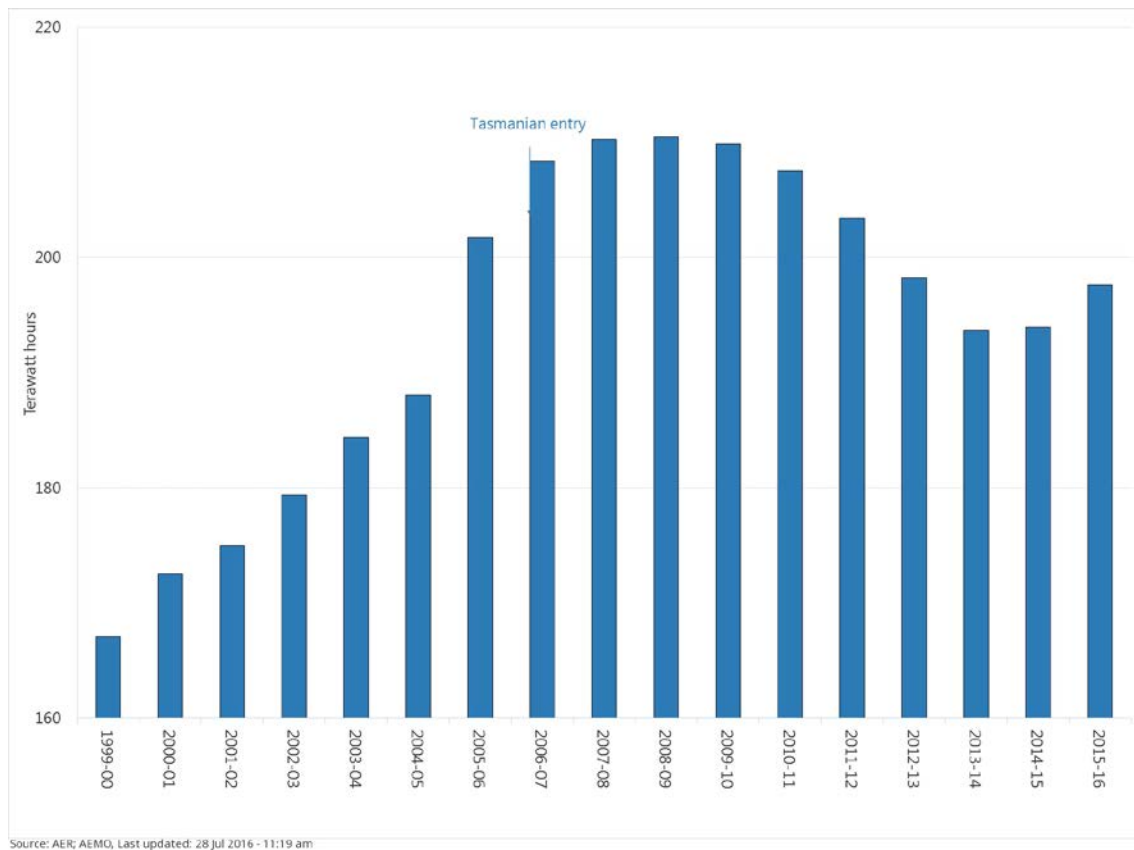
The electricity production and distribution process in a SC starts with the energy producers who mine, refine or process the required fuels (if fossil fuels are involved in the production). These may include gas, coal, nuclear-based fuels, or oil. The produced fuels are

transported to a power plant. Water used in hydroelectric plants is typically accumulated and stored in reservoirs close to the location of the plant. The electricity generated by a power plant is transmitted through high voltage transmission lines from the generators to the distribution network/grid operating on low voltage, which then delivers the electricity to the consumers (Dacruz and Martin, 2011; Reserve Bank of Australia, 2011). Electric power infrastructure refers to all physical elements of the production process including the power generation facilities and electric grids and networks distributing the power to the consumers. The generation and transmission systems may belong to a single company or different companies (Dacruz and Martin, 2011). Transmission over large distances could cause significant power losses, although the current transmission losses in Australia are at about 6% of the total output, which is below the World average at around 8% (The World Bank, 2016). Therefore, from the view-point of transmission losses, Australian EGDCs are not in a disadvantaged position. Figure 2.11 shows the discussed electricity chain flow.

An interesting fact that has the potential to impact on productivity and performance of electricity SCs and EGDCs in Australia was the reducing overall electricity consumption within NEM (Australian Energy Regulator, 2016). It could be seen that between 2008-2009 financial year and 2013-2014 financial year electricity consumption in Australia steadily reduced by about 10% (Fig. 2.12).

This was a very significant reduction in electricity consumption, which had the potential to reduce productivity of Australian EGDCs. Reducing consumption was likely to add to the difficulties with the effective adaptation of the centralised electricity systems to the challenges of the rapidly growing and fluctuating peak electricity demand and the growing contribution of the off-grid power supply systems, including solar power generation for individual households (Quezada, et al, 2014). The early signs of potential maladaptation of the electricity system in Australia demonstrated by Quezada, et al (2014) could have been

explained (at least partly) by the significantly reducing electricity consumption over the period of about 5 years – Fig. 2.12 (Australian Energy Regulator, 2016).



**Figure 2.12.** The illustration of the overall electricity consumption within NEM between 1999-2000 financial year and 2015-2016 financial year (Australian Energy Regulator, 2016).

This is one of the significant issues existing in the Australian power generation industry, which is related to the need for EGDCs to avoid potential maladaptation to the new environmental and operational conditions through (Barnett and O'Neill, 2010; Quezada, et al, 2014):

- the effective update of any legacy infrastructure, technology, government policies and regulations;
- adoption of new technologies and structures; and

- adaptation to any changing external factors such as climatic features, population changes, available resources and economic/social culture.

Failure on behalf of EGDCs and the government regulating authorities to address these issues in a timely and reasonable fashion threatens with reduced productivity within the industry and exposure to a variety of transitional risks (Rice Jr and Spayd, 2005; Chaudry et al, 2009; Froggatt and Lahn, 2010; Cherp et al., 2012; Lehner et al., 2012; Sioshansi, 2013; Mitchell and Watson, 2013; Hoggett, 2013, 2014; Gouveia, et al, 2014; Roelich, et al, 2014; Arent, et al, 2014; Eising, et al, 2014; Gracceva and Zeniewski, 2014; Portugal-Pereira and Esteban, 2014).

The discussed possible decrease in productivity within the electricity generation and distribution industry in Australia was corroborated by the finding of a significant deterioration of the country's productivity in the utility sector in recent years (Eslake and Walsh, 2011). From 2001 until 2010, the utility sector that covers the gas, electricity and water industries experienced a fall in the multi-factor productivity, which was around 3.7% annually (Eslake and Walsh, 2011). This decrease was supposed to be counteracted (at least partly) by the conducted deregulation of the electricity market in Australia, which was done in approximately the same period of time or earlier. However, the unfavourable market conditions associated with the transition to renewable energy sources and delayed adaptation of the major electricity providers could easily cause continuing productivity decline.

This was yet another significant motivation for the detailed analysis of the average productivity trends on the Australian electricity generation and distribution market to ensure evidence-based information is provided to the market operators and policy makers for possible actions towards improvement of the industry adaptation to changing conditions.

As indicated above, electricity SCs are typically established under a variety of technologies, equipment, fuels, linking infrastructure, and conditions dictated by government policies, social and environmental factors (Skea, et al, 2011; Dacruz and Martin, 2011; Pearson and Foxon, 2012; Busby, 2012; Unruh, 2002; Eadie and Elliott, 2013; Hoggett, 2013, 2014; Genus and Mafakheri, 2014). This is certainly the case in Australia (Eadie and Elliott, 2013), which significantly adds to the heterogeneity of the electricity providers and distributors on the Australian power generation market.

Further, Australian EGDCs are characterised by different levels of reliance on SC elements and network structure. Put differently, not all EGDCs on the Australian market can be qualified as SCs, and those that can be have different levels and complexity of SC networking. In accordance with the discussions in the previous section, different levels of engagement with, and reliance on, SC structures are likely to create different impacts on the productivity trends of the respective EGDCs.

This study did not intend to identify or conduct a detailed analysis of the specific impacts of SCs and SC elements on productivity of EGDCs. Instead, it was focused on the investigation of the productivity trends among significantly heterogeneous EGDCs, whether or not they could be qualified as SCs or might be parts of any larger SCs. Therefore, any impacts of electricity SCs and their elements on EGDC productivity trends were assumed to impact on the statistical grouping (categorisation) of EGDCs which was adopted and conducted in this study. At the same time, the conducted review of SCs and electricity SCs will be relevant to, and important for, the proper understanding and interpretation of the obtained results.

## 2.5 Summary

The undertaken literature review has revealed and demonstrated the essential need for the development and improvement of the methodological approaches to the evaluation and analysis of productivity trends in the electricity generation and distribution industry in Australia. The currently available knowledge suffers from significant gaps including the lack of specific and detailed understanding of the performance of this important Australian industry subsequent to the deregulation process. As was indicated in Section 2.1, knowing and properly understanding of the productivity trends in the industry should facilitate the government regulatory process to enable its smooth and successful transition to renewable energy sources (CCC, 2008; Foxon, 2011) under reduced energy security risks.

Major previous research efforts and significant body of literature have been focused on the determination of productivity, efficiency, and their growth relative to the best industry practices. However, there is still an on-going debate about the best methodology to analyse highly heterogeneous EGDC samples (Heshmati, et al, 2012), and particularly in the event of a relatively small company sample, like in Australia. This demonstrates the need for further development of suitable methodologies for the productivity analysis in the heterogeneous context of the national power generation markets.

The current lack of the detailed analysis of the average productivity trends as functions of EGDC parameters including company size on the Australian electricity market is a significant hindrance for the successful development of effective policies and regulations aimed at optimisation and rapid adaptation of EGDCs in Australia subsequent to the deregulation process. Only few rather limited in nature overseas attempts to conduct such an analysis – see, for example, Oh (2015) – do not give confidence about the applicability of the obtained outcomes and trends to the Australian power generation market. The apparently



declining productivity in the Australian power generation sector at least in the recent past (Eslake and Walsh, 2011), combined with the declining trends of electricity consumption (Australian Energy Regulator, 2016) and early signs of maladaptation of EGDCs to the new market conditions (Barnett and O'Neill, 2010; Quezada, et al, 2014), requires careful evidence-based management in order to avoid difficulties for the broader Australian economy. This served as a significant motivation for the current study aimed at arming the Australian policy and decision making bodies with adequate understanding of performance and productivity trends in the power generation industry.

The strong heterogeneity of Australian EGDCs creates a large number of variables and factors potentially impacting on the productivity and any its trends. Different levels of involvement of Australian EGDCs in electricity supply chains could be a noticeable addition to their heterogeneity, particularly after the deregulation process. Unfortunately, the analysis of SCs was often limited to the consideration of potentially contributing factors and with no any predictions of productivity trends or quantitative statistical comparison between the impacts of different identified factors on SC performance (Chen and Paulraj, 2004). The proposed SC framework (Chen and Paulraj, 2004) presented only a hypothetical network of expected impacts of the identified factors on each other, without any statistical proof and quantification of such impacts. Similarly, other research efforts, like by Wang and Cong (2012), also failed to provide any reasonable statistical analysis/modelling of variables or factors potentially having an impact on the performance of the proposed electric power supply chain networks. This significant gap in the current knowledge further adds to the difficulties and complexity of understanding of the production performance of Australian EGDCs, and further highlights the need for the detailed quantitative analysis of this performance. A significant contribution of the current study will be the development of predictive statistical methodologies based on mixed effects modelling and generalised

structural equation modelling allowing quantitative predictions of the average productivity trends for different EGDCs and EGDC categories (groups) in Australia.

## **Chapter 3. Cases of EGDCs**

This Chapter is effectively a continuation of the Literature Review, because it will present a review of the backgrounds and known characteristic features of the four typical examples of major electricity EGDCs in Australia: Origin, AGL, CS Energy and Snowy Hydro. These examples will provide further important insights into the regulations, strategies, economics, financial performance, productivity, and carbon regulation issues for each of the four companies. Thus the review conducted in this Chapter will represent an essential background for the subsequent qualitative analysis (based on the 4 examples of these companies) of the factors and influences capable of significantly impacting on the performance of EGDCs under the Australian environmental, business and regulatory conditions and frameworks.

### **3.1 Snowy Hydro Limited**

#### **3.1.1 Background**

Snowy Hydro Limited is an Australian EGDC that provides renewable electricity to the NEM. This energy is distributed through the wholesaler and a company owned retailer, Red Energy, to the end-users in different cities and regions of Australia. It is regarded as a highly innovative, strong financial and efficient business, which also has a good workplace culture. The company aims to become a sustainable EGDC by contributing towards the benefit and welfare of society. It involves different operating units throughout Australia, employing more than 650 employees. The growth of the NEM is concurrent with the growth of Snowy Hydro as it is the leading energy provider to this market (Snowy Hydro, 2012c).

### **3.1.2 Asset Portfolio**

Snowy Hydro EGDC has a wide operational base including:

- A combined hydroelectric power plant built under the Snowy Mountain Scheme (1950) of 3950 megawatt (MW) operating in Australia's Southern Alps;
- The Laverton North gas-fired power plant of 320 MW; and
- The Valley Power gas-fired power station of 300 MW operating in Victoria.

Along with the electricity generation facilities, the company also provides various other services such as voltage control, black start system, frequency regulator and emergency assistance. The company owned retailer, Red Energy, sells gas and electricity to consumers residing in New South Wales, Victoria and South Australia (Snowy Hydro, 2012c).

#### ***3.1.2.1 Snowy Mountain Scheme***

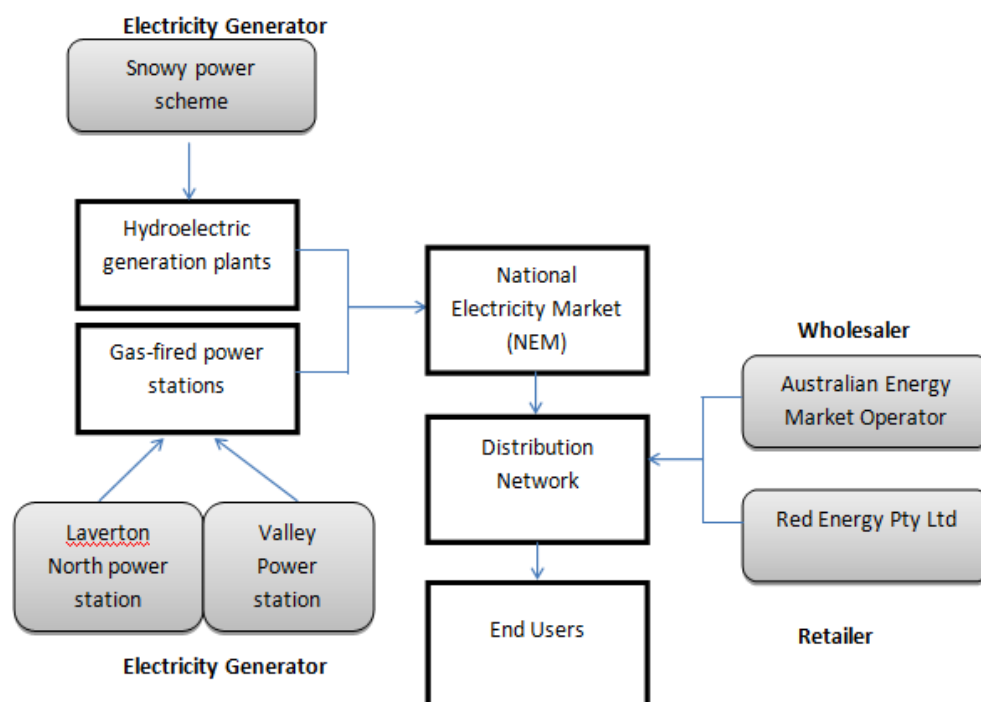
The Snowy Mountain Scheme has brought a new revolution in the world of energy in Australia. It took almost 25 years to develop (1949-1974). It now collects and stores water that would normally flow east, and diverts it through tunnels and power stations to provide renewable, pure and clean hydroelectricity to Australian cities. The water is then released into the Murrumbidgee and Murray River systems for irrigation purposes. This process is facilitated by a multifaceted integrated network consisting of seven main power stations, sixteen large dams, 80 km wide watercourses, and 145 km integrated passageways (Snowy Hydro, 2012c).

The Snowy Scheme produces up to 40% of the renewable and clean hydroelectric energy to the NEM, which accounts for 4500 GWh. This is a demonstration of the major contribution of this EGDC to the market of renewable electricity in Australia. This scheme

results in considerable savings in emission of carbon dioxide by up to 4,500,000 tonnes per year, which would have been produced, had the same amount of electricity been generated using fossil fuels (Snowy Hydro, 2012c).

### 3.1.3 Supply Chain of Snowy Hydro

Snowy Hydro retains several active and inactive (i.e., those that did not have any significant accounting transactions during an accounting period) subsidiaries. Controlled subsidiaries include the company owned retailers Red Energy Pty Ltd (Red Energy) and Valley Power Pty Ltd (Valley Power), as well as Snowy Hydro Trading Pty Ltd, Latrobe Valley BV and Contact Peaker Australia Pty Ltd. The Snowy Hydro has 100 per cent ownership in all these companies (Snowy Hydro, 2011).



**Figure 3.1.** SC structure of Snowy Hydro Pty Ltd (Snowy Hydro, 2012b).

Being a consolidated entity, Snowy Hydro manages and controls numerous plants and operations. The Snowy Mountains Hydro-electric Scheme is also managed and operated by

the Snowy Hydro Ltd. There are sixteen large dams and nine power stations that come under this scheme. These dams and stations are situated at Kosciuszko National Park (KNP). The two Victorian gas-fired power stations (Laverton North and Valley Power) are also operated within the supervision by the consolidated entity (Snowy Hydro, 2011).

The company's SC follows a vertical integration process. In total there are 8 gas-fired and 33 hydroelectric power stations of Snowy Hydro Limited that fulfil the daily energy demands of the energy retailers and consumers in NEM (Snowy Hydro, 2012a). Energy is passed on to a large customer base in NEM via Red Energy. In addition, Snowy Hydro serves as the energy wholesaler over vast regions of Australia. Figure 3.1 illustrates the major elements and structure of the Snowy Hydro SC.

### **3.1.4 Regulations**

Snowy Hydro adheres to the environmental principles, laws and policies of New South Wales and Victoria (Snowy Hydro, 2011). These laws and regulations are:

- National Parks and Wildlife Act (NSW) 1974
- Environmental Planning and Assessment Act (NSW) 1979
- Contaminated Lands Management Act (NSW) 1997
- Protection of the Environment Operations Act (NSW) 1997
- Environmental Protection and Biodiversity Conservation Act 1999
- Local Government Act 1993 (NSW)

The Snowy Management plan and the Kosciuszko Plan of Management handle the operations and functions of Snowy Hydro at KNP. Snowy Hydro could face a lawsuit under the listed acts in the event of not meeting the environmental regulations (Snowy Hydro,

2011). Any future development by Snowy Hydro is subject to the standard approval processes under the relevant legislations (Snowy Hydro, 2011).

The Snowy Water Licence has been issued to the company on the basis of the Act of Snowy Hydro Corporatisation 1997 (NSW). The gathering, storing, utilising and disposing of water from the Snowy field is guided through the use of this licence. Under the jurisdictions of the same licence, the company is also liable to consider the annual water releases for water users, environmental flows and flexibility for electricity generation within the Snowy Rivers region (NSW Office of Water, 2009).

### **3.1.5 Strategies for Change under Future Carbon Regulations**

According to Snowy Hydro, the new power plants and the existing energy generating processes will be significantly impacted by any potential reintroduction of carbon pricing, which may also impose uncertainties regarding future NEM contracts (IPART, 2012). The company seeks to pursue vertical integration by strengthening downstream SC arrangements in order to avoid any risk and uncertainty in the near future (Sustainable Water Strategy, 2012).

Snowy Hydro declared that investments would be constantly made into plants and equipment, aimed at bringing new irrigation technologies and power generation systems that could provide efficient energy to the end users at minimum cost. The indicated savings up to 4,500,000 tonnes of carbon emissions resulting from the reliance on hydroelectric plants could be considered as highly beneficial for the economy and existing environmental and climatic concerns (Snowy Hydro, 2012c). The company also seeks to adopt strategies for developing human capital, such as training and education programs, and to invest significant amount of capital into enhancing its business activities and operations (Snowy River Environmental Flows, 2011).

Greater reliance on renewable energy sources such as hydroelectric power, requires adequate management of risks associated with changing natural weather patterns and rainfall. In this respect, cloud seeding is a technique to modify the weather and cause rainfall by introducing a seeding agent into appropriate clouds (Snowy Hydro, 2015d). The cloud seeding program has proved to be a phenomenal success for Snowy Hydro (Snowy Hydro, 2015c,d). Therefore, it seeks to continually expand this program, and also aims to further develop its gas-fired power generation. This will further assist the company with optimising the use of the existing water resources and will also improve the irrigation timing and the ability to meet the customer demands (Snowy River Environmental Flows, 2011).

### **3.1.6 Economics**

Snowy Hydro is a leading provider of peak, renewable electricity to the NEM, with a wide operation base in different cities of Australia. Therefore, its hydroelectric and gas-fired power stations have a considerable impact on the economies in which they operate (Snowy Hydro, 2012c). The Snowy Hydro Scheme has made significant contributions to both the social and economic developments at the regional and federal levels including the following important aspects and relevant arguments:

- The hydroelectric infrastructure and its maintenance needs provide on-going regional socio-economic benefits, while having longer functional survival compared to thermal plants (Australian Bureau of Statistics, 2012).
- Operational costs of hydroelectric generating systems are relatively low compared to thermal plants burdened by on-going fuel costs that are subject to changing economic conditions (Australian Bureau of Statistics, 2012).
- The connection of the Scheme – since 1959 – by transmission lines to the electricity grids of NSW and Victoria has been economically advantageous as



this enabled sharing reserves and exchanging electricity between the states with optimisation of costs (Australian Bureau of Statistics, 2012).

- Snowy Hydro also assists in the underwriting of approximately \$2 billion of irrigate agriculture – without its guaranteed water supply a high proportion of the primary production in the area would not have been possible (Cousineau and Cammerman, 2008).
- Indirect outcomes included the tourism industry within the Snowy Mountains generating approximately \$439 million per year for the region – the Scheme’s scenic lakes and reservoirs are used for recreation by hundreds of thousands visitors (Cousineau, and Cammerman, 2008).

### **3.1.7 Financial Performance**

Snowy Hydro adopts accounting standard AASB 139, which protects the company and the undertakers of financial hedging contracts from the effects of market price volatility. The financial hedging contracts act as trading tools between buyers and sellers. The financial derivative tools for evaluation and predictive financial modelling are used to assist with the management decisions in the company, aimed at predicting and mitigating price risks and reasonably anticipating future outcomes and developments (Snowy Hydro, 2012a). For example, over some years, the NSW economy has been facing a constant downward trend in the energy and power prices (Anderson, et al, 2007). Fluctuating prices resulted in an increased risk faced by the company, making it important for Snowy Hydro to mitigate those risks. The company responded to these risks by anticipating the future price developments and through planning strategies lowering the risks. This has found its reflection in the company’s financial performance over recent years.

During 2008-2009, Snowy Hydro's operating environment was characterised by both low NEM volatility (alleviated by a small number of high-price events) and low water inflows. The company relied heavily on the gas-fired power stations and on recycling water – the costs involved in utilising these water resource risk hedges are reflected in Direct Costs of Revenue. For this period net profit after tax was \$211.9 million, which included a Mark to Market increase relating to price risk hedging contracts of \$52.3 million before tax. The 2009-2010 financial year saw a net profit after tax of \$266.9 million, which included an increase in market values of the consolidated entity's price risk hedging contracts of \$60.5 million before tax. There was a significant increase in NEM volatility during the 2010 period, particularly in NSW, and a moderate improvement in water inflows. The years 2011, 2012, 2013 and 2014 were characterised by low NEM volatility (alleviated by a small number of high-price events) and further substantial improvements in water inflows. The latest considered reporting period (2013-2014) showed a net profit after tax of \$495.5 million, which included the increase in the market value of the consolidated entity's price risk hedging contracts in the amount of \$323.7 million before tax (Snowy Hydro, 2015a).

Snowy hydroelectricity generation and water release has shown a remarkable increase from July 2009 to July 2014. In the 2008-2009 financial year, Snowy Hydro generated 3,333 GWh from gas and hydroelectric sources, and released 1,324 GL of water. Whereas, during the 2013-2014 period Snowy Hydro generated 3,850 GWh from gas and hydroelectric sources, and released 1,835 GL of water (Snowy Hydro, 2015a).

### **3.1.8 Productivity**

Snowy Hydro belongs to the capital-intensive industries where large investments are made in gas, energy, water, river flows, hydroelectric systems, etc. It is important for corporations like Snowy Hydro to ensure operational efficiency and higher productivity. The

financial performance of Snowy Hydro substantially improved from \$265.3 million in 2012-2013 to \$485.4 million in 2013-2014 (Snowy Hydro, 2015a). This increase in financial performance is likely attributable to the upgrade investments into a number of generating assets, and to various strategies employed by the company. For example, the peak power stations are activated for short periods to take advantage of any surge in wholesale electricity prices (Robins, 2014).

Snowy Hydro commenced a substantial modernisation program in 2006 to maximise the value of the Snowy Scheme hydro-generation assets. A major milestone of the Scheme Modernisation Project was reached in 2012 with the completion of the Tumut 3 power station upgrade. This upgrade costed over \$80 million for the replacement of the turbine runners and control systems, and refurbishment of the electrical and mechanical components. The upgrade enabled a 20% increase in the generating capacity of the station from 1500 MW to 1650 MW, with the maximum output up to 1800 MW under ideal conditions. The upgrade also allowed the company to benefit from a 3% increase in efficiency, i.e., greater power output from the same water flow (Snowy Hydro, 2013).

In 2012, modernisation work commenced at Murray 1 Power Station and continued until 2024. Year 2014 also saw the commencement of Tumut 1 and Tumut 2 power station modernisation (Snowy Hydro, 2013). It is expected that higher capacity turbine runners will increase efficiency by approximately 4%, with an additional 34 GWh generated annually from the same volume of water. The modernisation works of Tumut 1 are planned to conclude mid 2018 (Snowy Hydro, 2015b).

In addition, the previously mentioned Cloud Seeding Program is also expected to boost the productivity levels and make them less dependent upon the natural availability of water particularly during dry periods (Snowy Hydro, 2015d).

### **3.1.9 Conclusion**

Snowy Hydro has a significant SC network that operates throughout Australia. Overall, Snowy Hydro has been investing heavily and performing well within the changing external environment. The company represents an operator heavily investing in, and relying on, the production of clean sustainable electricity by supplying about 40% of renewable hydroelectric energy to the NEM, which is equivalent to around 4500 GWH.

The business model of Snowy Hydro is that of a major wholesaler of electricity in the NEM (Snowy Hydro, 2014). It gives Snowy Hydro a sustainable competitive advantage in the development of innovative management of electricity price risks. Furthermore, the company has location advantages due to its positioning between the major NSW and Victorian NEM energy end-users. The large capacity and highly flexible start/stop hydro and gas generation capability give the company the ability to draw on large scale generation at short notice, permitting the company to offer electricity price risk hedging contracts by generating electricity upon demand (Snowy Hydro, 2015c). At the same time, vulnerability of Snowy Hydro to significant drought effects impacting on water reserves should be regarded as one of the risks faced by this company.

In response to the business strategies of its competitors and to further reduce exposure to overall risks, Snowy Hydro intends to consider further gas-fired generation investments (particularly to mitigate environmental risks, such as extended droughts), environmental and water related products, and to grow its customer base (Snowy Hydro, 2014).

## **3.2 AGL**

### **3.2.1 Background**

AGL is one of the largest privately owned and operated Energy Company in Australia. The company's headquarters are located in New South Wales, and it has more than 2000 employees (AGL, 2012). AGL is an integrated renewable energy company that operates retail energy businesses, power generation assets, and an upstream gas portfolio (AGL Energy Ltd., 2013).

In the recent decades, one of the major goals of AGL has been the development of sustainable energy sources, along with the reliable energy distribution to its customers. Although the majority of AGL's investments were in hydro and wind energy sources, the company was also involved in the continuous development of other renewable sources including geothermal, solar, biomass, landfill gas and bagasse. With over three million customer accounts, AGL operates a significant percentage of Australia's energy retail, upstream gas and merchant energy businesses (AER, 2012a).

### **3.2.2 Asset Portfolio**

The power generation portfolio of AGL has been diverse, and includes the basic power supply and peak demand, with a variety of generation plants incorporating traditional thermal generation and renewable sources such as hydro, wind, landfill gas and biomass (AGL Energy, 2013).

AGL's hydroelectric scheme is located in Australian Alps, Victoria. It covers four power stations that have the total capacity of 381 MW:

- McKay Creek power station (150 MW);
- Clover power station (29 MW);

- West Kiewa power station (62 MW); and
- Bogong power station (140 MW).

The new hydroelectric generator in Bogong is the largest generator built in Australia in the last 3 decades, and it provides renewable electricity to over 120,000 homes during summer peak demand (AGL, 2009).

AGL has also invested in a number of wind farms that represent one of the most effective and cheapest forms of renewable energy, although still lagging, in terms of its costs, behind large-scale solar PV generation and hydroelectric power (Ramblingsdc, 2012). AGL wind farms produce electricity without fuel costs, have no GHG emissions and do not pollute the air. These farms are one of the most significant energy sources in South Australia, and they make a considerable contribution towards achievement of the national renewable energy targets (AGL, 2009). AGL continuously invests in renewable power generation sources as part of its long-term strategy. It currently owns four wind farms with a total capacity of 389 MW (AGL, 2009, 2012):

- AGL Hallet 1 Wind Farm: started production in June 2008 – consists of 45 turbines with the total generation capacity of 94.5 MW;
- AGL Hallet 2 Wind Farm: opened in late 2009 – consists of 34 turbines with the total generation capacity of 71.4 MW;
- Wattle Point Wind Farm: consists of 55 turbines with the generation capacity of 90.8 MW; and
- AGL Hallet 4 Wind Farm: completed in 2011 with the total capacity of 132.3 MW.

Among other assets of AGL are also the following gas-fired power stations:

- Torrens Island power station: the largest Australian power station fired by natural gas, with 8 steam turbines and the total capacity of 1,280 MW; and
- Somerton power station: built in 2002 with 4 gas-fired turbines and the total capacity of 150 MW.

In accordance with the AGL development plans, a third of the Loy Yang Power Station and its coal mine were acquired in 2004. It supplies about 1/3 of the total electricity needed in Victoria and is the largest base load energy generator in the area. The remaining 67% of the Loy Yang Power Station was acquired by AGL in 2012, making the company the sole owner of the power station (Reuters, 2012):

- Loy Yang coal-fired power station: total capacity of 2,200 MW.

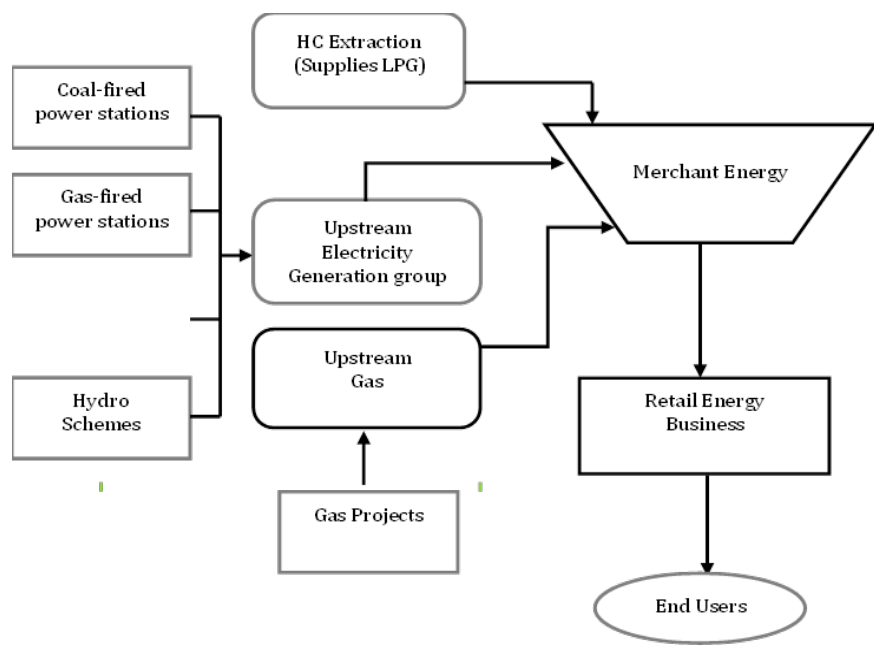
During the last decade, the company has also invested heavily in gas projects, and the current AGL asset portfolio includes the following gas installations:

- The Gloucester Basin Gas Project focusing on the development of coal gas resources including gas wells installations, construction of a central facility for processing, and construction of a pipeline for gas transportation;
- The Sydney Basin Gas Projects consisting of the Camden, Hunter and Sydney projects; and
- 50% ownership of the Moranbah Gas Project that is the largest coal-seam methane project in Australia supplying about 12% of the total gas market in Queensland (AGL, 2009).

### **3.2.3 Supply Chain of AGL**

AGL is a vertically integrated electricity retailer (i.e., it owns electricity generation assets as well as a retail business) within the NEM. In addition to its electricity business AGL

operates a gas production and retail business (AGL Energy Ltd., 2013). AGL produces upstream gas and electricity through various power plants and thermal stations. Merchant Energy is a separate business unit of AGL, which is responsible for the management of the company's LPG and electricity supplies. LPG is produced by HC Extractions and upstream gas projects (gas stations at Surat, Cooper and other geo-thermal power plants (AGL, 2012)), and electricity is generated at the power plants, after which both gas and electricity are delivered to Merchant Energy and then transferred to the Retail Energy unit (also a business unit of AGL) supplying electricity and gas to the customers or end users (Fig. 3.2). The Retail Energy unit is responsible for distributing electricity in Queensland, New South Wales, Victoria and South Australia. The unit Upstream Gas unit manages and develops AGL's upstream gas assets located in Queensland and NSW (AGL Energy Ltd., 2014). The final links are the end consumers/users (Fig. 3.2), represented by residents, small business companies or commercial and industrial projects that use the electricity.



**Figure 3.2.** AGL SC Network



Realising that the SC and its effective management can significantly influence the overall business performance of a company, AGL has invested significantly into the resources and various policies with the purpose of better control over its SC and thus, security of operations in general. Although most of its generated power is based on wind and hydroelectric sources, AGL still depends upon a variety of producers that supply the company with natural gas from Cooper Basin, Bass Strait, and Queensland's Surat/Bowen Basin (Perl and Mewett, 2008; Baker, 2013; AGL, 2015c). To ensure continuous and reliable supply, AGL entered into long-term contracts with each of these producers.

For additional supply security, the company started to use a natural underground facility for gas storage (AGL, 2016a), which will be located in the Bowen Surat Basin in central Queensland, and the Newcastle Gas Storage Facility (AGL, 2016b). In addition, the company owns and operates other projects for coal seam gas, including the Gloucester and Hunter Valley projects (AGL, 2011), aiming at securing a sufficient future gas supply.

A dedicated Produced Water Management Strategy was developed by AGL in 2011, with the purpose of protecting surface and ground water and to enable sustainability of water resources (AGL, 2011). The main goal of the strategy is to provide means for increasing the amount of reused water for any applicable primary and secondary production activities within the company. As part of this strategy, networks for monitoring water were placed in the areas of explorations in Gloucester, Galilee and Hunter.

### **3.2.4 Regulations**

As a privately-owned company and part of the NEM, AGL closely complies with the regulations set by the Australian Government and NEM for generating and operating electricity. The main rules and regulations for operation within the NEM have been set

forward by the Australian Energy Market Commission, including (AGL, 2012; DSEWPC, 2012):

- Environment Protection and Biodiversity Conservation 1999 Act;
- Sustainable Planning Act 2009;
- NSW Petroleum (Onshore) Act 1991;
- NSW Environmental Planning and Assessment Act 1979;
- NSW Protection of the Environment Operations Act 1997; and
- NSW Water Management Act 2000.

Compliance with the government laws and other applicable regulations is ensured through AGL's Department for Regulation and Policy, which also implements corporate governance within the company (AGL, 2012). In addition, the company is a full member of the Energy Supply Association of Australia (ESAA), under which AGL is supporting the energy market reform including the maintenance of a transparent and competitive energy market policy, and compliance with the GHG emissions reduction policy (ESAA, 2012).

In the area of carbon emission, AGL closely follows several relevant national regulations, the most important of which are (DCCEE, 2012):

- National Greenhouse and Energy Reporting Act 2007;
- Carbon Pollution Reduction Scheme;
- Expanded Renewable Energy Target; and
- National Framework for Energy Efficiency.

### **3.2.5 Strategies for Change under Future Carbon Regulations**

There are three main drivers that significantly influence the future strategies of AGL: climate change, energy security, and fuel reserves. In parallel with these drivers and the

global push for using renewable energy, AGL continuously makes considerable investments and adjusts its strategies with the purpose of following the trends and contributing to the national policies and guidelines. Although there have been considerable diversity and alterations of the Australian government policies with regard to the introduction of renewable energy sources, AGL remained committed to the renewable energy future through the various investments and implemented strategies. These involved an investment in excess of \$3 billion in renewable energy generation making AGL one of the largest developers of renewable energy in the low-carbon dedicated environment (AGL, 2013b). In 2011 the average CO<sub>2</sub>-e emission of AGL's generation fleet was about 58% below that of the NEM, while several new projects for renewable power generation and low-emission gas were also commenced. AGL plans to continue its shift towards renewable energy sources, including through its ongoing investments, a long-term strategy, and the development and promotion of a conceptual single clean energy obligation on the national level (EcoGeneration, 2011; Nelson, Simshauser, Orton and Kelley, 2012; AGL, 2013b). AGL continues to determine and balance its investments on the basis of the appreciation of depleting fossil fuels, generally raising energy prices, and significantly increasing number of individual customers that spend more than 10% of their monthly income on energy (AGL, 2010).

Hence, the future strategies of the company are aligned mostly towards the ability of AGL to respond to the environmental, social, and economic challenges. The company's efforts in adopting and implementing practices for sustainability reporting have helped AGL improve its operations in many areas. The GHG emission reporting, policy development and disclosure have been of particular significance in the preparation of the company for possible future emission trading schemes (AGL, 2010). Three major approaches are used by the company in the area of measuring and publication of its GHG emissions performance. These approaches are the Operational, Equity, and Energy Supply Footprint, giving three separate

accounts of the impact of the company's operations on annual national GHG emissions (AGL Annual Report, 2012).

As a result of this awareness and implementation of a long-term strategy, AGL has been able to achieve several strategic investments, which have intensely reduced the GHG emissions of the company. It was expected that, by 2010, 78% of the total company's generation capacity will have very low or no emission at all (AGL, 2010). The company's future strategy is set on increasing this percentage up to around 93% as a result of its developmental investments (AGL, 2010).

The adopted strategy towards renewable sources of energy resulted in a highly favourable position of AGL with regard to such a transition and/or any future possible low-carbon regulations and requirements (Australian Government, 2011; Carbon Tax, 2012). The company's considerable investments in renewable energy in the recent decades may prove to be a considerable competitive advantage for AGL in future, as the company is expected to own or operate approximately 1,420 MW of renewable energy assets (Productivity Commission, 2012).

### **3.2.6 Economics**

AGL Energy Limited is an integrated company for renewable energy and its main focus is the sales and purchase of gas and electricity. It consists of merchant and retail energy business, assets for power generation, and a portfolio for upstream gas. Additionally, it conveys explorative, extraction, production and sales of gas activities. Therefore, AGL has a considerable impact on the economies in which they operate:

- The highest gas users in the Greater Newcastle region, NSW, contribute approximately \$2 billion to the local economy (AGL Energy, 2014b).

- The Gloucester Gas Project will create several hundreds of jobs during the construction, commissioning and operational phases (AGL Energy, 2014c).
- The Newcastle Gas Storage Facility is vital to the economic and social welfare of the region, as the developed energy infrastructure will provide greater gas supply security, generate economic benefits during the construction, commissioning and operational phases, and will support the emerging coal seam gas industry in the surrounding regions (AGL Energy, 2014c).
- AGL is focusing on achieving retail economies of scale through a service platform capable of supporting approximately five million customers (AGL Energy, 2014c).

### **3.2.7 Financial Performance**

During the 2008-2009 period, AGL's Retail Energy and Merchant Energy businesses produced strong Earnings Before Interest and Tax (EBIT) in difficult market conditions (AGL Energy, 2015). For this period underlying net profit after tax was \$378.8 million. The 2009-2010 period saw a 13.2% increase in the underlying net profit after tax to \$428.9 million. During the 2009-2010 periods AGL's Retail Energy delivered strong growth in operating EBIT while the Merchant Energy performed well in the mild market conditions. AGL's underlying net profit after tax for the 2010-2011 financial year was \$431.1 million, an increase of 0.5% from the previous year, reflecting the effects of the unusual summer weather experienced in Eastern Australia. The 2012 and 2013 saw continued increases in the underlying net profit after tax. However, the 2013-2014 reporting period showed a 3.9% decrease in underlying net profit after tax of \$562 million, which was probably related to the overall decline in the energy consumption in Australia (Fig. 2.12). In addition, the earnings during the 2013-2014 financial year were probably affected by the record warm winter

weather conditions (AGL Energy Ltd., 2015). Consistent with reduced earnings, AGL's electricity generation and gas volumes have decreased from July 2009 to July 2014. For example, in the 2008-2009 financial period AGL generated 33,966 GWh of electricity and provided 223.3 PJ in gas, whereas during the 2013-2014 period AGL generated 27,802 GWh of electricity and provided 204.2 PJ in gas (AGL Energy Ltd., 2015).

### **3.2.8 Productivity**

The earning potential of AGL is influenced by many factors, including the operational efficiency of the assets and their availability and ability to kick in quickly and reliably when electricity prices are high (AGL Energy, 2013b). In general, the availability and start reliability of AGL's generation assets show strong performance. The operational performance of the gas-fired and hydro-generation assets (e.g., 95% reliability for Dartmouth and 92% for Eliden) were strong by industry standards in 2013 (AGL Energy, 2013b).

The costs of the merchant operations increased in 2011, due to higher labour costs, costs associated with commissioning a new plant, higher maintenance costs for the power generation assets, higher depreciation, and others (AGL, 2011).

Increases in productivity have resulted from the major maintenance programs and plant enhancements at the Loy Yang power station, which resulted in an increase in generation capability from 2000 MW to 2200 MW. A \$60 million conversion project completed in 2014 converted all Loy Yang operating units from ageing analogue systems to digital control systems, which was vital to ensure energy security and supply reliability (AGL Energy, 2015b). Energy savings for these stations is estimated at approximately 3 million GJ (AGL Energy, 2013b). Liddell power station has also benefited from technology upgrades, resulting in significant operational and environmental gains (AGL Energy, 2015b). Repairing

process improvements at the Torrens power station allowed AGL to save further ~ 15,000 GJ of energy during the 2013 financial year (AGL Energy Ltd., 2013b).

### **3.2.9 Conclusion**

In addition to supplying its customers with reliable electric power (with over three million energy customer accounts), the main aim of AGL has been the development of sustainable power supply and sources. The company has been able to capture a significant percentage of Australia's power retail, upstream gas and merchant energy market.

Considering the power generation portfolio, the company has been able to establish a diverse and vast base. Apart from its hydro based power stations, AGL has also invested heavily in wind farms, which enabled it to generate energy in the most cheapest and efficient ways using renewable sources. AGL continuously invests in renewable power generation sources as part of its long-term strategy, which means that the company in future will be able to survive more effectively in the market, and is less likely to be detrimentally impacted by policies such as carbon prices.

The main competitive advantage of AGL is that it is both an energy producer and retailer. Therefore, AGL does not have to go to the wholesale market to purchase energy, which is beneficial unless the wholesale price falls below AGL's cost of production (Mudie, 2015). AGL has been able to establish a leading position in the market, due to which it has been able to perform well financially in a sustainable way.

### **3.3 CS Energy**

#### **3.3.1 Background**

CS Energy is a corporation wholly owned by the Queensland Government, which is engaged in the production of electricity in Queensland for the state and national markets. CS Energy runs both gas-fired and coal-fired power stations for upstream supply. All electricity produced by CS Energy's power stations is sold to retailers in the NEM, which then sell this energy to consumers and households (CS Energy 2011).

#### **3.3.2 Asset Portfolio**

CS Energy is responsible for a number of independent power stations that produce a total capacity of 3,570 MW (CS Energy, 2004, 2010a, 2011, 2015):

- Callide coal-fired power stations:
  - Callide A (120 MW);
  - Callide B (700 MW); and
  - Callide C (405 MW).
- Kogan Creek power stations:
  - Kogan Creek coal-fired power station (750 MW); and
  - Kogan Creek Solar Boost Project (44,000 MWH of electricity per year).
- Mica Creek gas-fired power station (1692 GWH as in 2010/2011):
  - Mica Creek A power station:
    - Units 1-4: 132 MW of power.
    - Units 5-7: 103 MW of power.



- Mica Creek B power station: 35 MW of power.
- Mica Creek C power station: 55 MW of power.
- Swanbank power stations:
  - Swanbank B coal-fired power station: 480 MW of power;
  - Swanbank E gas-fired power station: 385 MW of power.
  - Swanbank ReOrganic Energy project: uses landfill gas to co-fire with coal at Swanbank B power station; the produced gas ensures approximately 5 MW of electricity.

#### *3.3.2.1 Callide Power Stations*

The black coal used for the Callide power stations is taken from the nearby Callide coal fields (CS Energy, 2010a,b, 2011). Ash produced by the coal-fired electricity generation process finds its further use in the construction industry; for example, 92,386 tons of ash was supplied to Cement Australia and Mansell in 2010/2011 (CS Energy, 2010a,b, 2011).

The majority of the water that is used at the Callide power stations is derived from the Gladstone Area Water Board's Awoonga Dam and is transported via pipeline to the Callide Dam for the purposes of minimising evaporation. Some additional minimal water is taken from SunWater's Callide Dam, with potable water being taken from the Banana Shire (CS Energy, 2010a,b, 2011).

The Callide A power station is the location of a world-leading \$200 million clean energy coal project, the Callide Oxyfuel Project, which involves retrofitting a Callide A power station unit with the oxyfuel technology, enabling carbon dioxide to be captured and stored underground. This illustrates the possibility of producing electricity from coal with nearly zero carbon emissions (CS Energy, 2010a,b, 2011).

### *3.3.2.2 Kogan Creek Power Station*

During the 2010/2011 financial period, Kogan Mine supplied 2.5 million tons of high-quality, low-sulphur black coal to the power station. CS Energy also completed work on the Out of Pit Ash Cell at the Kogan Mine, which serves as a permanent storage facility for the ash produced at the power station (CS Energy, 2010a, 2011).

In April 2011, the \$104.7 million Kogan Creek Solar Boost Project was launched (CS Energy, 2011). This project allowed for a maximum output of 44 MW during peak solar conditions, and up to 44,000 MWH of electricity per year, which is enough to power 5,000 households (CS Energy, 2010a, 2011). This project serves to increase the electricity output and fuel efficiency of the Kogan Creek power station alongside with the station's feedwater system. The Compact Linear Fresnel Reflector technology will be used in order to heat the feed water entering the boiler, which will serve to supplement the conventional coal-fired heating process (CS Energy, 2011). This addition of solar power will allow the Kogan Creek power station to produce a greater amount of electricity without having to use any additional coal, thus serving to increase the fuel efficiency of the coal-fired plant and reducing the greenhouse emission (CS Energy, 2011).

It is estimated that the Solar Boost Project will generate enough electricity to prevent the release of 35,600 tons of GHG each year - equivalent to removing 11,000 cars from the road (CS Energy, 2011).

### *3.3.2.3 Mica Creek Power Station*

The gas-fired Mica Creek power station is the main source of power for the Mount Isa and Cloncurry regions. The full generation capacity of the Mica Creek power station is fully contracted at this point. Therefore, while the power plant is currently able to meet the customer demand, an upgrade of the power station will be required in order to meet future

demand and to replace the older units which are nearing the end of their economic life (CS Energy, 2011). As of the end of June 2011, CS Energy submitted offers for long-term power supply to customers, involving Xstrata and Ergon Energy, in order to determine the optimal power supply solution for the region (CS Energy, 2011). An upgrade of the 325 MW power stations would allow for the continuation of a secure, reliable, and efficient power supply derived in future. The proposed upgrade involves the retiring of four older units currently being used, and replacing them with new efficient 120 MW units (CS Energy, 2010a, 2011).

Mica Creek power station uses gas derived from Santos' South West Queensland fields, which is transported to the power station via the Carpentaria Pipeline (CS Energy 2010a,b, 2011). The water used for the station is derived from the Leichhardt supply system and Rifle Creek Dam. This water is cycled up to 12 times in total through the power station and provides water for reuse by Xstrata mining operations. In 2010/2011, 394.5 mega litres of water were delivered to the mine (CS Energy, 2011).

#### *3.3.2.4 Swanbank Power Stations*

The Swanbank A power station – a coal-fired station – was decommissioned in August 2005. Four units of the Swanbank B power station – also a coal-fired station – were decommissioned in 2010-2012, due to the end of their operational life.

The coal supplied to the Swanbank B power station was derived from the New Hope Corporation's Acland open cut mine on the Darling Downs (CS Energy, 2010a, 2011). The Swanbank power station derived most of its water from the Western Corridor Recycled Water Project at Bundamba (CS Energy, 2011). Small quantities of water were also pumped from the Bremer River at Berrys Lagoon during periods of heavy rain, while water from the Wivenhoe system was no longer needed.

Swanbank C and D were only small gas-fired power stations, with Swanbank D running only for a couple of years (Engineers Australia, 2016). Swanbank E is a much bigger gas-fired power station. It derives its gas from the coal seam methane gas fields located in Scotia, Spring Gully, Berwyndale, and Kogan North fields (CS Energy, 2011). This power station sources the majority of its water from the Western Corridor Recycled Water Project at Bundamba (CS Energy, 2011).

CS Energy also operates the Swanbank ReOrganic Energy project, which was a project producing landfill gas to co-fire with coal at Swanbank B power station. This was one of Australia's largest waste-to-energy projects, with the gas producing approximately 5 MW of electricity. This project reduced GHG emissions by a total of more than 3,000,000 tons of carbon dioxide (CS Energy, 2011).

CS Energy is an active member of the Ash Development Association of Australia and serves to promote the recycling of power station fly ash (CS Energy, 2011). Approximately 60,000 tons fly ash obtained from the Swanbank B power station was supplied to Pozzolanite and Ipswich Motorway Upgrade Project (CS Energy, 2011), along with crusher dust and cement. These products were used to form a solid fill underneath the 8 km stretch of the Ipswich Motorway project from Dinmore to Goodna. Furthermore, CS Energy is also working alongside the Queensland Government on feasibility of using fly ash to fill mine voids at Collingwood Park. Work is also being done on the disposal of ash to the Swanbank ash dam (CS Energy, 2010a, 2011).

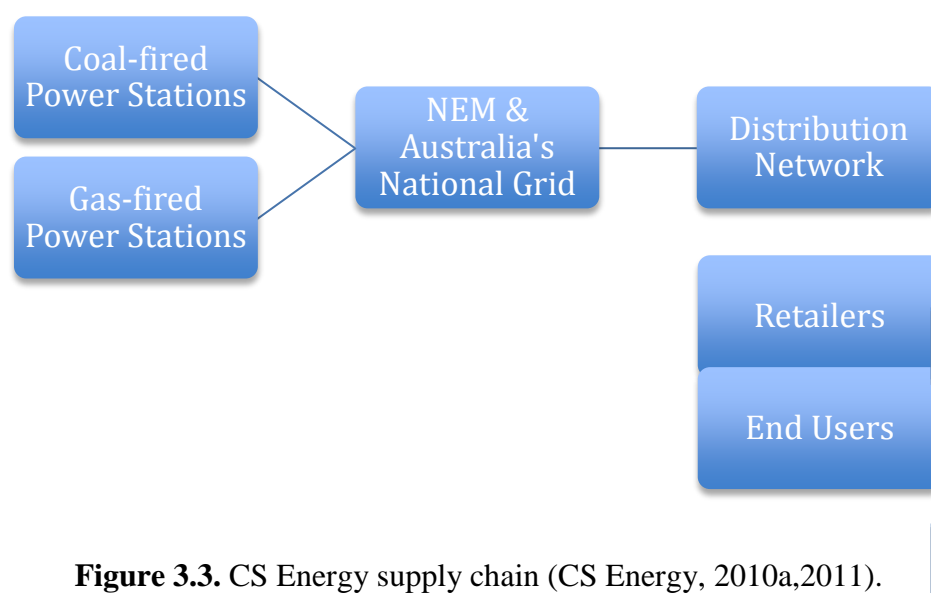
#### *3.3.2.5 Coal Seam Methane Gas*

CS Energy also established a joint venture arrangement with Arrow Energy in order to develop a coal seam methane gas field that would be capable of producing a total of approximately 4 PJ of gas over a period of 15 years (CS Energy, 2011). The Kogan North gas

field also saw a slight increase in gas production to a total of approximately 3.4 PJ per year. At the end of June 2011, the top 10 highest producing wells within the Kogan North gas field were producing approximately 70% of CS Energy's total gas requirements (CS Energy, 2011).

### 3.3.3 CS Energy Supply Chain

CS Energy used both gas-fired and coal-fired power plants (CS Energy, 2011). The coal and gas required to fuel these power stations were sourced from various coalfields, mines, and coal seam methane gas fields. All electricity produced by CS Energy's power stations is sold to retailers in the Australian national grid, and is subsequently sold to consumers including households (CS Energy, 2011) – see Fig. 3.3.



**Figure 3.3.** CS Energy supply chain (CS Energy, 2010a,2011).

### 3.3.4 Regulations

CS Energy adheres to the principles included in the Minimum Employment, Industrial Relations and Job Security Principles for Employees of Government Owned Corporations

(CS Energy, 2011). CS Energy and its employees are governed by the following acts (CS Energy 2011):

- Government Owned Corporations Act 1993;
- Electricity Act 1994;
- Regulation of 2006; and
- Fair Work Act 2009.

The activities of CS Energy are subject to the environmental regulations under the Commonwealth jurisdiction and legislations regarding the operation and the expansion of its power stations. The main state environmental laws that focus on these types of activities are as follows:

- Environmental Protection Act 1994 (Queensland); and
- Sustainable Planning Act 2009 (Queensland) (CS Energy 2011).

During the 2010/2011 financial year, CS Energy stated that minimising any environmental impact that their activities have is an important priority to them (CS Energy, 2011). One of the specific goals of CS energy is to produce fewer than two significant reportable environmental incidents per year (CS Energy, 2011). Corporate strategies utilised in order to help achieve this target include (CS Energy, 2011):

- The maintenance of an ISO14001 environmental management system across all sites;
- The development of abatement and offsetting measures to offset the percentage of the total amount of carbon emissions produced;
- Participation in industry forums that focus on key issues including emissions;
- Research and development;

- The pursuit of continuing improvements in sustainability management and performance through the improvement of emission output, resource management, water conservation and waste management at all sites; and
- Sustainable development and use of efficient resources and social responsibility in all procurement activities.

Within CS Energy, the Boards Major Capital and Technical Committee has ultimate responsibility for managing any potential risks for CS Energy, as well as ensuring compliance with all relevant laws, regulations, and policies (CS Energy, 2011). Internal audits, risk management, insurance oversight and general compliance are incorporated within the functions of the Board Major Capital and Technical Committee. Additionally, staff and directors are encouraged to make reports of any conduct observed which they may believe to be a possible breach of the CS Energy policies or any external regulations or laws. A specific process for responding to any disclosures and associated confidentiality provisions for individuals making the disclosure are contained within the CS Energy Procedure guidelines for Pecuniary Interest, Conflict of Interests and Protected Disclosure (CS Energy, 2011).

### **3.3.5 Strategies for Change and Future Carbon Regulations**

As part of its 2010/2011 Business Plan, CS Energy tailored its strategies to develop a portfolio that contains the following:

- By 2020, have 300 MW of renewable generation and be carbon neutral in its internal energy consumption.
- By 2030, achieve a generation portfolio greenhouse emission intensity of less than 400 kilograms of CO<sub>2</sub>-e per MWh.

While CS Energy has one of the leading roles in the development of renewable and low emission technology in Australia, its targets for renewable generation and installed capacity

were revised in response to market conditions and the eventual repealing of the carbon tax and emissions trading schemes. The above-indicated company's renewable generation target of 300 MW was actually a revision down from 500 MW due to uncertainty concerning a national carbon policy.

CS Energy has incorporated a number of different strategies for change, including the use of renewable energy sources and innovative in-house strategies, including ash recycling as well as water conservation, supplementary solar power pre-heaters of the water used in coal-fired process, and a number of water conservation and recycling strategies and initiatives (CS Energy, 2010a, 2011). This included the completion (in 2010-2011 financial year) of a three-year environmental study that focused on the monitoring of the use of recycled water at the Swanbank power stations (CS Energy, /2011).

### **3.3.6 Economics**

CS Energy is a fully corporatised government trading enterprise that is subject to competitive neutrality principles. These principles require the company to operate under the same commercial principles as a privately-owned company.

CS Energy is a major employer in the Queensland's regional communities and, as such, contributes to the economic, social and cultural life within these communities. CS Energy takes an active role in supporting local economic development within communities that support their operations (CS Energy, 2004). For example, for the Kogan Creek Power Project a Local Industry Participation Plan has been developed to maximise the opportunity for local suppliers and contractors to participate in the project and contribute to both the regional and Queensland economies (CS Energy, 2004).



### **3.3.7 Financial Performance**

During the 2008-2009 periods, CS Energy's net profit after tax was \$93.8 million, reflecting an increase in the level of generation from the power station assets, following the first full year of operation of the Kogan Creek A power station (CS Energy, 2015). The 2009-2010 periods saw a net loss of \$47.6 million, resulting from unplanned outages, reduced load output and poor coal quality impacting on the power station performances. CS Energy continued to struggle during the 2011, 2012 and 2013 years, resulting from low plant reliability, coal supply issues, unfavourable market conditions, low average pool prices and falling contract prices. The 2013-2014 reporting period showed a net loss after tax of \$59.9 million, an increased loss of \$12 million from the previous year. This loss reflected lower generation due to on-going coal supply issues, lower pool price and reduced volatility within the NEM (CS Energy, 2015).

CS Energy's generation has shown a decrease from July 2009 to July 2014. In the 2008-2009 financial period CS Energy generated 17,974 GWh of power, whilst during the 2013-2014 financial period its generation dropped to 15,203 GWh (CS Energy, 2015). The 30% reduction was consistent with, but significantly exceeded, the levels of consumption decline in the same years – Fig. 2.12 (Australian Energy regulator, 2016). This demonstrates that the financial position and performance of CS Energy could be regarded as significantly lower than those of the other considered example companies including Snowy Hydro, AGL and Origin (see below).

### **3.3.8 Productivity**

In response to the reduction in coal supply, CS Energy adopted strategies to manage low coal risks including the following (CS Energy, 2015):

- Maximising the efficiency of operating plants;
- Utilising the limited coal in periods of highest demand and price;
- Placing Callide Power Station B generating units in reserve storage during low demand periods; and
- Some expansion into solar energy research and production, illustrated by the Kogan Creek Solar Boost Project in 2011.

CS Energy conducted assessments on their generating assets in 2013/2014 and identified a number of energy efficiency opportunities which are being implemented or examined further (CS Energy, 2015).

### **3.3.9 Conclusion**

CS Energy appears to be more reliant on coal sources and has not been able to establish a sustainable image in the same way as other competitors such as Snowy Hydro, AGL and Origin. The company's power stations including Kogan Creek, Callide Power Station and Swanbank B Power Station relied on the use of black coal as a source. However, the company made some investments into gas-fired stations such as Mica Creek and Swanbank E power stations. In 2011, CS Energy showed its interest in minimising environmental impact of its activities. The report published by the company (CS Energy, 2011) showed that by the year 2020, it aimed to have 300 MW of renewable generation and become carbon neutral in its internal energy consumption. This demonstrated the intention of CS Energy to significantly reduce its footprint and to take steps towards operating in a more environmentally friendly fashion. However, these targets were put in doubt as a result of repealing carbon tax in 2014.

The significant reduction in CS Energy's power generation in 2009-2014 and the related decline in the company's financial position demonstrated its difficulties with the

adaptation to the new environmental and market conditions (Barnett and O'Neill, 2010; Eslake and Walsh, 2011; Quezada, et al, 2014).

### **3.4 Origin Energy**

#### **3.4.1 Background**

Origin Energy is the leading integrated energy company in Australia. Two of the major types of its business activities are the generation and retailing (supply) of electricity. Other operations include the exploration and production of oil and gas. Origin has also invested into the renewable power sector, for example, in hydro, geothermal, solar and wind. Origin is characterised by a significant diversity of its operations including the following different areas (Origin, 2012a-e):

- Electricity generation;
- Exploration and production of oil and gas;
- Contact energy;
- Retailing of energy; and
- Renewable energy production.

This diversity means this company is highly integrated, unlike many other EGDCs on the Australian electricity market.

Consistent with the current pace of globalisation, Origin has extensive operations in Australia and New Zealand and is considering investing in different countries where there is a potential for growth in the power sectors, especially in Asia (Origin, 2012a-e). The sustainability of the business operations is one of the most important considerations for the company. Due to the huge investment in renewable energy and technologies, it is regarded as the largest retailer of “green” energy in Australia and New Zealand. Origin also operates a

portfolio of onshore and offshore gas and energy exploration licenses, and has expanded into different regions of Central Australia to cater for increasing demands of customers and the energy sector (Oil and Gas Review, 2012).

### **3.4.2 Supply Chain of Origin**

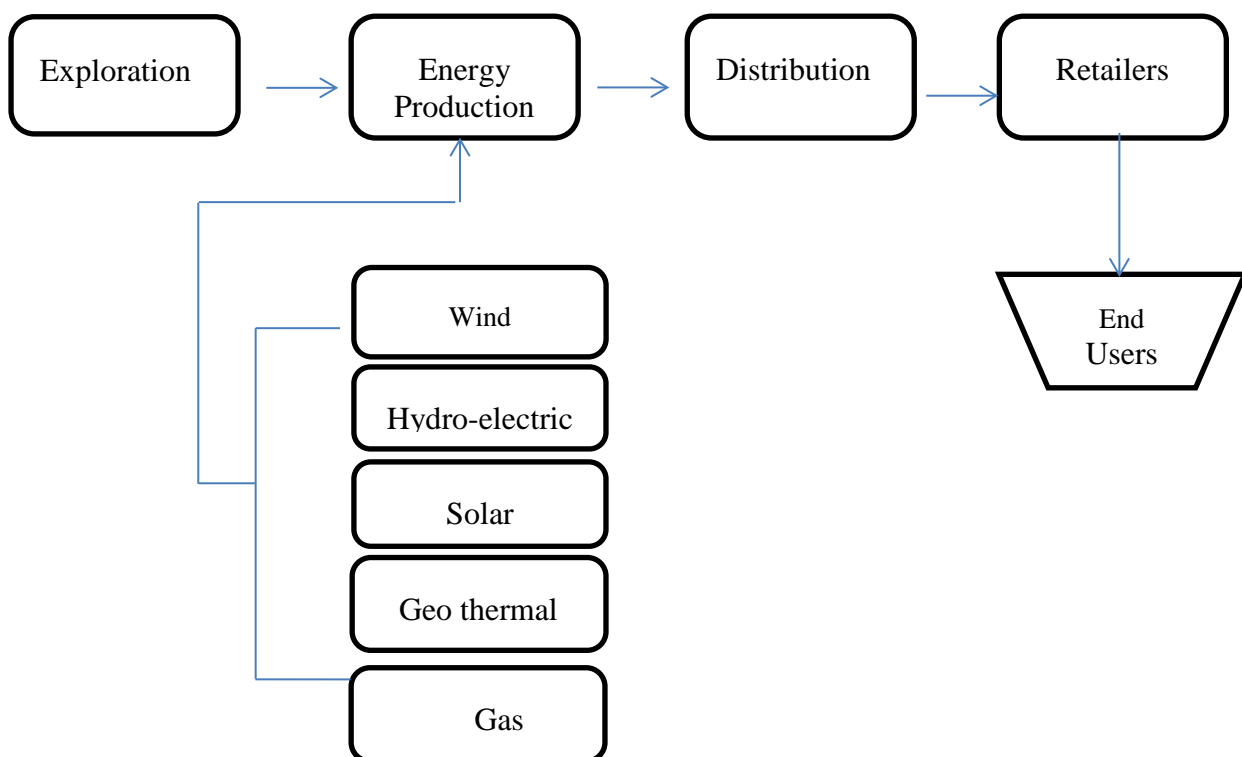
As one of the Australia's leading integrated energy companies, Origin operations span from gas exploration and production to power generation and energy retailing. The company has significant renewable energy investments including wind, geothermal, solar and hydro. It is renowned as a “green energy producer and retailer”. The company tends to capitalise on the retailing and exploration capabilities to pursue long-term growth in all its activities (Resource Channel, 2012).

There are different exploration licenses that are performed under the Origin activities, including in the areas of Surat, Eromanga/Cooper basins and Bowen located in Central Australia, Bonaparte Basin and Perth Basin in WA, and Bass Basins and Otway in Southern Australia. Origin also contains the portfolio of onshore activities that are particularly focused on gas exploration and generation (Oil and Gas Review, 2012). In addition, to these diversified assets, Origin also has a wind farm in Cullerin Range in New South Wales for producing renewable energy.

To gain an understanding of the Origin operations, it is important to consider the four areas of activities (Origin Sustainability Report, 2012):

- Exploration;
- Production (generation);
- Distribution; and
- Retailing (sale).

These areas are performed across the gas and energy components of Origin. Gas purchased from different sources by Origin is sold directly to customers through wholesaling and retailing. The power that is generated by the company at different power plants located across central, northern and southern Australia is distributed to wholesalers, retailers, or directly to the Origin customers (Origin Sustainability Report, 2012) – Fig. 3.4.



**Figure 3.4.** Origin SC

### 3.4.3 Regulations

The complexity and diversity of the Origin operations impose significant obligations on the company to comply with a variety of different relevant laws and regulations. The company created a Regulatory Compliance Management System to meet its regulatory compliance (Origin Sustainability Report, 2012). This system operates through an electronic

compliance database that determines all the relevant aspects of the regulatory framework. This framework includes Commonwealth legislative framework, state and territory regulations and legislations. Origin also adheres, and is committed, to the existing health and safety requirements, and encourages its customers to do the same through provision of the following safety advices (Origin Sustainability Report, 2012):

- Safety warnings and precautions on the LPG supply and storage facilities for pouring of the LPG.
- Safety regulations and warnings on company websites for its customers to safely and securely handle the services of the company including natural gas, electric power, and LPG.
- The distribution points of LPG also distribute brochures on customer safe handling and pouring of LPG.
- The Emergency Service Centre for customers provides advice on the safe use of LPG and other company products. In case of emergency, customers can also contact the service centre.

#### **3.4.4 Strategies for Change and Future Carbon Regulations**

The major focus of Origin's business strategy is to provide green and renewable energy resources for its customer and considerably reduce CO<sub>2</sub>e emissions. The company has specific targets to reduced emission levels, which guide the company planning, operations and business strategies (Origin Sustainability Report, 2012). One of the company goals is to boost the accuracy and efficacy of the measurements and reporting standards for GHG emissions. Origin bases its future development, performance and prosperity on economic avenues aimed at significant reductions of GHG emissions and carbon footprint (Origin Sustainability Report, 2012).

A particular role in the successful fulfilment of this Origin's goal is expected from the wind generation projects and significant investments in the development of solar energy projects (Origin Sustainability Report, 2012). Origin maintains that these projects will be particularly helpful for the company in maintaining its carbon efficient portfolio. The significant research and development projects are also focused on the reduction of carbon emissions from fossil fuels, such as coal, gas and oil, and to improve carbon-efficiency of the existing power generation plants (Origin Sustainability Report, 2012).

### **3.4.5 Economics**

Origin provides power to different zones of Australia and New Zealand. The remarkable diversity of its operations and research and development projects over vast areas of Australia and New Zealand (including significant regional areas) significantly contributes to the important role this company actively plays in the broader Australian economy and communities (Origin Sustainability Report, 2012). The community benefits from Origin operations and activities include the following (Origin Energy, 2015):

- Enhanced employment opportunities, particularly in the regional and remote areas;
- Participating in provision of local goods and services;
- Investing in local infrastructure and regional development, including, as an example, about \$10 million investment in June 2014 on the community development in the Surat Basin region with 765 Origin employees; and
- Contributing to Australia federal and local taxes and royalties.

### **3.4.6 Financial Performance**

Origin maintained its significant profitability and excellent performance over many years, including the period when the power and energy prices in Australia were on decline (Anderson, et al, 2007). During the 2010-2011 period, Origin's underlying profit increased 15% to \$673 million, reflecting its successful investments in the generation, exploration, and production businesses during the previous two years, including the acquired NSW power businesses (Origin Energy, 2015b). The 2011-2012 financial period saw a further significant profit increase by 33% to \$893 million, which was driven by a lower exploration expense, higher commodity prices, and a full year contribution from the NSW energy assets acquired in 2011. The 2012-2013 period saw the underlying profit decrease by 15% to 760 million. This decrease reflected the previously discussed general reduction of energy consumption in Australia (Australian Energy regulator, 2016), an increase in underlying net financing costs, and higher underlying depreciation and amortisation charges. The 2013-2014 reporting period showed a further mild decrease of the company's profits by 6% to \$713 million (Origin Energy, 2015b).

One of the significant moves undertaken by the company in the recent past was its decision to sell a portion of its oil and gas condensate for the total amount of around \$287 million. This was aimed at retiring of company's debts and further boosting Origin's financial and market position (Origin Energy, 2012). This decision demonstrated the company's ability to make significant moves to improve management of the company, its assets and market position.

The development and commissioning of the Darling Downs Power Station in July 2010 was another Origin's investment initiative aiming at strengthening its retail business activities and market position. This caused a significant shift in the company's business



performance, including rapid increase of the revenue in the subsequent years through boosting Origin's retail activities and its customer base. The development of this new power plant has also increased generation company's capacity from 1,620 MW to 2,250 MW (Origin, 2012b,d,e).

Origin continuously seeks to expand and diversify its existing portfolio of energy and fuel resources. This strategy helped boosting its revenue and cash flows through an expansion of the diversified operations to a variety of territories and locations in Australia and overseas (Origin Sustainability Report, 2012).

### **3.4.7 Productivity**

The productivity of Origin is shown by its generally excellent performance and business outcomes. The significantly diverse energy sources and technologies employed by Origin have driven its productivity to the levels typically exceeding the national average. Origin continuously and actively seeks new business opportunities through making significant investments in exploration and new renewable energy technologies, which created a significantly beneficial internal environment to enhance its productivity and production efficiency (Australian Energy Regulator, 2012). At the same time, the significant focus on exploration of, and investment in, renewable energy sources could also present a challenge for Origin, as the associated additional investment expenditure has the potential to cause short-term competitive difficulties in relation to other companies primarily focused on coal-fired generation plants (State of the Energy Market, 2011). Based on the observed Origin's excellent performance and financial status over a number of years, it is possible to conclude that this company has been highly successful in adequately balancing its investments (aimed at the future productivity increases under the changing environmental and social conditions) with the obtained revenue and cash flows.

The current projects in renewable energy exploration and development including several power plants in Australia and New Zealand have significantly strengthened the Origin's business network. This has considerably helped Origin to achieve its sustainability objectives in an efficient manner (Origin Sustainability Report, 2012). The focus on the 'green' power has enabled Origin to achieve high levels of production in renewable energy, which cannot be easily matched by its competitors. Thus, Origin has a wide and diverse operational base that ensures its high current and future productivity and competitiveness on the Australian power market, and enables its efficient transition to renewable energy sources (Origin Sustainability Report, 2012).

### **3.4.8 Conclusion**

Overall, it can be said that Origin Energy is one of the leading integrated and diversified power companies in Australia. Although its main activity is the retailing of energy and generation of power, Origin's business portfolios in exploration, gas and oil production, and renewable energy research and development make this company highly efficient and resilient to environmental and social risks it might face.

Origin has made significant investments in the renewable power sector including hydroelectricity, geothermal, solar and wind energy. Origin has responded to the increased rate of globalisation by its investments into various countries, which further strengthen its production and financial base. Due to the company's focus on the provision of green and renewable power, combined with the effective management and decision making, Origin has been able to demonstrate excellent financial performance and significantly secured its future productivity and competitiveness under the challenging market conditions.

## Chapter 4. Methodology and Data

This Chapter presents the description of the data and major research methodologies used in this study, including the statistical approaches to data analysis, data collection techniques and sample discussions. Three different statistical methodologies will be involved in this research, including cluster analysis techniques, standard mixed effect regression analysis, and generalised structural equation model (GSEM) with mixed effects. The considered data sample will involve 30 electricity companies (EGDCs) operating on the Australian electricity supply market, including their major performance variables and ratios.

As was explained in Section 2.2, the research on productivity in different industries has been primarily focused on the accurate determination of productivity and efficiency of production units, companies and industries. The final outcome of most papers in this area was the calculated value of the productivity variable. Very limited efforts (such as, for example, by Oh (2015)) have so far been focused on the determination and analysis of average productivity trends and dependences on multiple variables and factors, and particularly under the Australian conditions in the electricity-generating sector. At the same time, average productivity behaviour and its predictions for an industry sector or a group of similar companies would be important for the decision-making and policy-making bodies in their evaluation of industry performance and development of effective regulatory measures stimulating further growth. This was the major motivation and reason in this study for using the methodology described below in this Chapter, aimed at the quantitative analysis of temporal trends of productivity and performance as functions of the major company characteristics and factors in the power-generating sector in Australia.

## **4.1 Data Collection and Variable Description**

As outlined in the Introduction (Chapter 1), Australia's energy industry used to be comprised of a single government owned business for generation, transportation and distribution of electricity (Australian Energy Regulator, 2014). This energy industry has been completely transformed, with the public monopolies split up by the government, resulting in the industry now consisting of numerous generation and distribution private and public business entities (Australian Energy Regulator, 2014). In New South Wales, Queensland, the Australian Capital Territory, Tasmania and South Australia, the National Electricity Market (NEM) was established on 13 December 1998. The NEM allows power to flow across state borders to meet the demand of customers in other jurisdictions (Australian Energy Regulator, 2010). The NEM operates in the form of a competitive spot market in which the adjustments in the prices are made in real time in line with the demand and supply conditions (Australian Energy Regulator, 2014). This has resulted in extensive competition within the industry.

Because one of the major goals of this study was to highlight the major characteristics and performance of EGDCs in Australia and to make a showcase for the respective statistical methodology (Section 1.4), the simplest approach to calculate partial productivity on the basis of Eq. (1.1) was used. We were not concerned with the identification of the industry best practices through the use of frontier analysis (Section 2.2). This was because we were rather interested in the average behaviour of productivity and its major trends for statistically determined EGDC categories (see below).

Therefore, in accordance with the general aim of this study (Chapter 1), the first step was the collection of suitable data evaluating and characterising performance of different EGDCs operating on the Australian power-generating market. Thirty-six different EGDCs were originally selected for this study, which was done primarily based on availability of the

required performance parameters. The performance data was collected mainly from the annual reports produced by the selected EGDCs, generation industry reports, and reports and information provided by the Australian Bureau of Statistics (ABS).

Data collection was undertaken over the six year period between 2006-2007 and 2011-2012 financial years to ensure reasonable evaluation of the evolutionary performance trends occurring in the electricity supply industry in Australia, and to evaluate the undertaken fragmentation of the electricity supply market. This particular period of data collection was chosen because of the following reasons:

1. Prior to 2007:

- the power-generating market in Australia was highly stable with a significant proportion of government ownership of assets and companies, which made the productivity analysis less useful and practical;
- our major research goal was to evaluate productivity trends after significant privatisation of the industry, and develop recommendations for possible regulatory policies subsequent to the privatisation; and
- the consistent historic productivity-related data and other company characteristics were difficult to find and verify prior to 2007, particularly for government-owned companies.

2. After 2012:

- this period of time was characterised by the significant instability of the power-generating market in Australia, which was largely related to the Australian Emissions Trading Scheme (or Carbon Tax) introduced on 1 July 2012 (Australian Government, 2011);

- Carbon Tax had a dramatic transitory impact on Australian EGDCs, including:
    - numerous company mergers and horizontal integration;
    - numerous asset sales and acquisitions;
    - industry diversification; and
    - development and introduction of new technologies;
  - this was considered as a transitory and temporary environment whose consideration was not within the scope of this study aiming at the evaluation of productivity trends subsequent to market deregulation and development of the relevant useful methodologies.
3. Because of changes in reporting standards and information provided in annual reports, it was difficult to collect the consistent complete datasets characterising company performance over a longer period of time.

Six of the total of 36 EGDCs originally involved in the database did not have (because of different reasons) reasonably complete sets of the required performance data over the whole considered study period, or were not managed entirely as an Australian entity. Such companies were discarded from the analysis, leaving the sample of 30 companies with the relatively complete datasets (with only a few missing data points – Appendix 1). Any complete or partial mergers between the companies were considered as part of the normal development process, and were not discriminated in the analysis, as long as the acceptable company performance data was available for the complete indicated study period.

The major performance variables collected into the database (Appendix 1) were as follows:

- *Output*, which is the overall yearly electricity output (in GWh) for EGDC.

- *Revenue*, which is also called turnover and is EGDC's income received from electricity sales over the period of 1 year.
- *Employee Cost* (EC), which is defined as a total of the basic salaries, employment taxes and benefits for all EGDC employees associated with the electricity generation and/or distribution.
- *Employee Number* (EN), which is the total number of employees involved in the electricity generation and/or distribution within EGDC.
- *EBITDA*, which is EGDC's earnings before interest, taxes, depreciation, and amortisation.
- *Cost of Sale*, which is defined as the direct costs involved in generating the net revenue associated with the electricity generation and/or distribution.
- *PP&E*, which is property, plant & equipment that are EGDC assets involved in, and associated with, the electricity generation and/or distribution, which cannot be easily liquidated.

These original variables will be used in any statistical modelling within this study to classify EGDCs in the database and evaluate any distinct performance trends on the Australian electricity generation and distribution market. At the same time, the two additional derivative variables that are very often used to characterise company performance and efficiency are:

- $$\text{Capital Productivity} = \frac{\text{Output}}{\text{PP \& E}}, \text{ and} \quad (4.1)$$

- $$\text{Labour Productivity} = \frac{\text{Output}}{\text{EC}}. \quad (4.2)$$

Note that this definition of Labour Productivity is somewhat different from the more conventional definition as the amount of the Output per one hour of labour (Investopedia,

2016c). This definition alteration was adopted for this study because of the difficulties with identifying the total number of labour hours for each considered EGDC, and because the altered definition provides a similar performance characteristic – the Output relative to the employee involvement in the form of Employee Cost.

These two types of productivities will be the major focus of this study. However, the statistical modelling will be conducted using the original indicated variables, and the two productivities will then be derived from the developed models to provide the conventional performance characteristics. This approach will be adopted in this study because the direct consideration of the derivative variables (such ratios of the original variables in labour and capital productivities) in the statistical models is likely to cause information loss (e.g., information about any possible direct and indirect effects of the original variables) and does not present any distinct advantages over the consideration of the original variables.

The data presented in Appendix 1 was collected for each particular year (from the annual reports an/or other available sources) in the Australian dollars current to the year corresponding to the data entries. Therefore, prior to the analysis, any data entries in Appendix 1 measured in dollars (including PP&E, EBITDA, Revenue, Employee Cost and Cost of Sales) were adjusted to the inflation rates current to each particular year. This was done to ensure correct evaluations of the considered partial productivities of interest, including any their trends or dependences. In particular, positive inflation rates effectively reduce the growth of employee costs and PP&E.

Year	2007	2008	2009	2010	2011	2012
Inflation Rate	2.3	4.4	1.8	2.8	3.3	1.8

**Table 4.1.** Yearly inflation rates in Australia over the period of observations.



Inflation rate is typically calculated using the consumer price index and is determined as a percentage variation of this index (Boskin, 2008). The inflation rates in Australia are given in Table 4.1. The simplest approximate (but sufficient for the purpose of our evaluations and analysis) relationship between the percentage inflation rate  $I_Y$  in year  $Y$  and the costs  $x_Y$  and  $x_{Y-1}$  of an item or product in years  $Y$  and  $Y - 1$ , respectively, is given by the equation:

$$I_Y = \frac{x_Y - x_{Y-1}}{x_{Y-1}} \times 100\%. \quad (4.3)$$

Assuming that  $x$  is PP&E or EC, this equation gives the values of these variables in year  $Y - 1$  in the year  $Y$  dollars (i.e., adjusted to inflation):

$$\left[ (PP \& E)_{Y-1} \right]_{adj} = \left( 1 + \frac{I_Y}{100} \right) (PP \& E)_{Y-1}; \quad (4.4)$$

$$\left[ (EC)_{Y-1} \right]_{adj} = \left( 1 + \frac{I_Y}{100} \right) (EC)_{Y-1}. \quad (4.5)$$

With the known inflation rates in Australia (Table 4.1), we used Eqs. (4.4) and (4.5) to recalculate, for example, PP&E and EC in Appendix 1 for the years 2007, 2008, 2009, 2010 and 2011 in the year 2012 dollars (i.e., adjust these variables to inflation). Although there was only a very small effect of inflation on the developed models (limited to around 1% variation of the regression coefficients), the statistical models below in Chapter 6 were developed with the data adjusted to the inflation rates. At the same time, the summary statistics and EGDC classification (categorisation) (Chapter 5) were done with the original data in Appendix 1 before its adjustment to inflation.

## 4.2 Statistical Methodology

The statistical analyses were conducted using the Stata 13 statistical software package (StataCorp, 2013). The major goal was to reasonably classify (categorise) the available EGDCs and conduct a detailed analysis of any possible performance trends within each such category and across different categories. Therefore, the first methodological step was the statistical classification (categorisation) of the considered 30 EGDCs operating on the Australian electricity supply market. This are based on the three different types of cluster analysis (Rabe-Hesketh and Everitt, 2007):

- Principal component analysis (PCA);
- Average Linkage clustering; and
- $k$ -means clustering.

Because the available sample of Australian EGDCs was relatively small (30 EGDCs – see Appendix 1), we independently used these three different clustering approaches in order to validate the obtained outcomes (categorisation) of EGDCs. As will be seen in the next Chapter, the outcomes from all three clustering methods were quite similar, which confirmed and validated the proposed EGDC clustering (categorisation).

### 4.2.1 Cluster Analysis

#### Principal Component Analysis (PCA)

Each company is characterised by the performance variables (Appendix 1). However, it is quite difficult to directly evaluate these variables and properly understand which of them are particularly important for the characterisation of the companies and their mutual commonalities and/or differences. This is particularly the case because the available variables could be in significant correlations with each other, which means that they may be non-

orthogonal. Therefore, it is appropriate and convenient to construct suitable linear combinations of the available variables, which would be orthogonal to each other and could be considered as new variables suitable for a better (clearer) characterisation of the considered companies.

The described procedure is achieved through the application of PCA (Rabe-Hesketh and Everitt, 2007). This statistical approach evaluates the available observed variables (Appendix 1) and constructs new sets of independent orthogonal (i.e., mutually independent and uncorrelated) variables – principal components or factors – which can then be used for the characterisation and classification of the companies. In PCA, linear combinations of the standardised observed variables (Appendix 1) are created (Gorsuch, 1983; Fabrigar et al., 1999; Rabe-Hesketh and Everitt, 2007; Norris and Lecavalier, 2009). The coefficients in these linear combinations are adjusted and chosen in such a way that these linear combinations are orthogonal to each other. Thus, a new set of independent variables (principal components or factors) is created for the considered EGDCs. The name ‘principal component’ arises from the fact that the created orthogonal linear combinations characterise some important company characteristics that can only be expressed as properly constructed linear combinations of the original variables presented in Appendix 1. This is the reason why principal components calculated using the PCA approach provide significant advantages for company characterisation, including their potential clustering (Gorsuch, 1983; Fabrigar et al., 1999; Rabe-Hesketh and Everitt, 2007; Norris and Lecavalier, 2009).

Mathematically, in addition to the imposed condition that the principal components must not correlate with each other, they should also be chosen as explained below (Gorsuch, 1983; Rabe-Hesketh and Everitt, 2007). The original observed variables are standardised so that the average value for each of them is equal to zero and variance is equal to one. The first principal component (a linear combination of the standardised original variables) is chosen to

account for the maximum portion of the total variance of the standardised observed variables. The second principal component is then selected in such a way that it accounts for the maximum portion of the remaining (still unaccounted) total variance of the observed variables, etc. In accordance with this sequence, the determined principal components will have progressively reduced importance in describing the observed variables. Therefore, it is typically sufficient to choose only a few most important principal components that will describe the majority of the variance of the standardised observed variables (Gorsuch, 1983; Fabrigar et al., 1999; Rabe-Hesketh and Everitt, 2007; Norris and Lecavalier, 2009). The number of such most important principal components is often significantly smaller than the original number of the observed variables (Appendix 1). This is another advantage of PCA, as it allows a reduction (in some cases significant) of the number of the original variables, and this may significantly simplify the whole problem.

An approximate but very simple Kaiser Criterion (Kaiser and Rice, 1974; Gorsuch, 1983; Stevens, 2002; Rabe-Hesketh and Everitt, 2007) can be used to evaluate which of the principal components should be retained. Only those principal components are retained whose eigenvalues are greater than or equal to one. The eigenvalue is the amount of variance explained/extracted by the corresponding principal component. Therefore, the Kaiser criterion is equivalent to the rule that, unless a principle component extracts at least as much variance as one original standardised variable, we drop it. In our case, only the first two principal components will satisfy the Kaiser criterion and will thus be retained in the analysis (see Table 5.1 in Section 5.1.1 in the next Chapter).

Principal components are numerical variables characterised by their scores that are calculated from the values of the original variables (Appendix 1), and the linear combinations of those original variables determining the principal components (Everitt, 1994; Rabe-Hesketh and Everitt, 2007). If there are only two principal components with the major

contributions to the variance of the data (as in our case of EGDC characterisation), these two principal components, termed as PC1 and PC2, can be used to construct a single scatter-plot with PC2 on the vertical axis and PC1 on the horizontal axis. Different EGDCs will then be characterised by points on this scatter plot. The distance between these points on the scatter plot will be a quantitative measure of the difference between the corresponding EGDCs (Everitt, 1994; Rabe-Hesketh and Everitt, 2007). This gives us a useful tool to statistically identify clusters of dots (similar EGDCs) on the produced scatter plot.

#### *Other Cluster Analysis Approaches*

There are different types of cluster analysis in statistics, and the described PCA is one of them. The other two useful types are, as indicated above, the average linkage clustering method and *k*-means clustering (Calinski and Harabasz, 1974; Rabe-Hesketh and Everitt, 2007). A variety of clustering methods arises because of the different ways in which the distance between a cluster containing several observations and a single observation, or between two clusters, can be defined (Rabe-Hesketh and Everitt, 2007). These methodological differences enable independent use of different clustering methods with the aim of the subsequent comparison and, thus, validation of the outcomes.

In the average linkage method, distance between two clusters is defined as the average of all distances between all pairs of observations where one member of the pair is in the first cluster and the other in the second cluster. Typically, the distance between the members inside a cluster should be smaller than the distance between different clusters, which creates a series of hierarchical classifications of the observations (Rabe-Hesketh and Everitt, 2007). The outcomes of this method are often represented using a tree diagram or ‘dendrogram’ that, when cut off at some selected level, leaves us with the identified clusters. The number of identified clusters will thus be determined by the cut-off level that is typically chosen using the Duda and Hart index (Rabe-Hesketh and Everitt, 2007).

The *k*-means clustering approach uses an iterative procedure for the determination which group a particular observation belongs to based on calculating the distance between this observation and all groups (clusters). Several iterations are typically required to ensure that the observations do not change groups, in which case, the procedure is considered as complete. In this case, the number of groups (clusters) is determined using the Calinski and Harabasz approach to ensure the best possible fit to the available data (Rabe-Hesketh and Everitt, 2007).

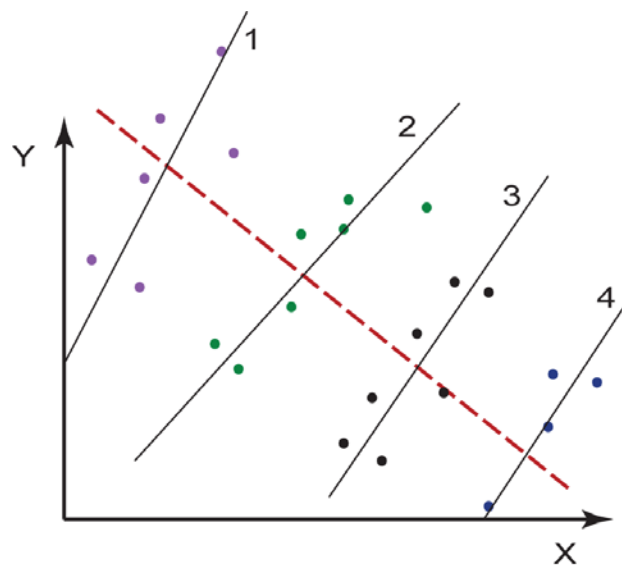
#### **4.2.2 Mixed Effects Model**

The described cluster analyses are typically regarded as exploratory data analysis techniques indicating possible groupings or clustering of the data. These methods are primarily used to generate hypotheses and suggest mutual characteristics, which subsequently need to be confirmed through more rigorous statistical tests or models.

The goal of this research was to determine, characterise and understand the major existing trends and performance characteristics within the Australian electricity generation and distribution industry. As the result, this study involved 30 different EGDCs currently operating on the Australian market. Each of these EGDCs displays distinct performance characteristics while operating under distinctly different and specific conditions within its own niche on the market. As a result, it is natural that each EGDC is significantly different from all the others, and its performance data over the six years of observations will be significantly influenced by the fact that this data belongs to the selected EGDC. For example, if one EGDC has significantly lower PP&E in a particular year than some other EGDC, it is likely that this difference would remain similar during the next year. In other words, the data points for the same EGDC corresponding to different years correlate with each other, because they belong to the same EGDC. Such kind of data requires the so-called mixed effects (or,

equivalently, random effects) regression modelling, where the term ‘mixed effects’ stands for different intercepts and/or slopes of the regression lines corresponding to different EGDCs.

An example illustrating the nature of mixed effects and the need for their proper statistical modelling is shown in Fig. 4.1. This figure is plotted for a hypothetical set of data with the two variables  $Y$  and  $X$ . Importantly; the considered dataset is constructed of the data from four different entities (e.g., EGDCs). If the standard regression analysis with no mixed effects is used, we obtain the dashed red regression line (Fig. 4.1). However, this dependence is obviously incorrect, as the correct dependences for the four entities are shown by the black regression lines 1 – 4 (Fig. 4.1). These are the significant differences between the four entities (different intercepts and slopes) that cause the incorrect regression outcomes in the form of the red dashed line if the hypothetical dataset is considered without mixed effects.



**Figure 4.1.** Note: Illustration of the nature of mixed effects and the need for their appropriate statistical modelling on the basis of the hypothetical dataset with the two variables  $Y$  versus  $X$ . The dashed red line represents the incorrect regression modelling outcome in the absence of mixed effects; solid black lines (lines 1–4) represent the correct regression outcomes in the presence of mixed effects. The different dot colours indicate the different entities (e.g., EGDCs) involved in the analysis. ‘Mixed effects’ are different (random) intercepts and slopes of the regression lines corresponding to different entities.

Typically, the most important part of mixed effects is random intercepts that actually determine the ‘starting point’ for the regression line (Fig. 4.1), and typically the greatest differences between the EGDCs. Therefore, the analysis of mixed effects in the form of random intercepts is the essential aspect of any regression analysis that considers multiple distinct entities (like EGDCs) over an extended period of time (in our case, a 6-year interval). Note that the analysis of the separate subsets of data corresponding to separate entities (EGDCs) is not possible because of the would-be insufficient sample size. Therefore, the only outcome of this difficulty is the consideration of the whole dataset with all 30 EGDCs by means of the mixed effects regression modelling.

One of the applicability conditions for a mixed effects regression model is the normal (or near-normal) Gaussian distribution of the dependent variables (in our case, Output). However, none of the numerical variables in the considered database (Appendix 1) was normally distributed. Therefore, all the numerical variables in the database, except for Year and Employee Number, were logarithmically transformed to approximate normal distributions.

### **4.2.3 Generalised Structural Equation Model (GSEM)**

One of the difficulties of the standard mixed effect regression models is that they may be poorly suited for the analysis of independent variables that significantly correlate with each other, in which case some of the dependent variables may show artificially low statistical significance. In addition, mixed effects models do not show mutual influences of the independent variables on each other, which could create difficulties with the identification of paths and causes of impacts of variables and factors, and for the determination of their direct and indirect effects on each other and on the dependent variable(s).



In the event of such difficulties and in the presence of significantly correlated independent variables, other statistical models, such as structural equation modelling (SEM), are typically used to allow the proper identification and analysis of chain-like interaction between the variables. In this model, an independent variable may have direct and indirect effects on other variables. An indirect effect occurs where an independent variable affects another independent variable, and this second independent variable influences the dependent variable. We say in this case that the first independent variable has an indirect effect on the dependent variable through the mediation of the second independent variable. Indirect effects may occur through one or more mediating variables. All possible paths for direct and indirect effects in an SEM structure can be identified through consecutive connecting arrows between the involved variables.

One of the significant difficulties with the SEM analysis is that it does not normally allow involvement of categorical variables (EGDC categories) and mixed effects, which, as has been explained above, were essential in this study. Fortunately, Stata13 software package used for this study includes the generalised SEM (GSEM) package that was specifically designed to allow the inclusion of categorical variables and mixed effects (which was one of the reasons for choosing the Stata13 package for this research).

GSEM structures are very similar to SEM structures with indicated paths for the direct and indirect effects. At the same time, GSEM structures allow use of mixed effects regressions in each relationship for any pair of significantly related variables (including categorical variables). In the GSEM modelling conducted to identify major general trends for the whole industry and selected categories of EGDCs mixed effects were highly significant (and were, in fact, used) in each of the identified significant relationships.

As indicated above in this section, one of the significant benefits of SEM and GSEM is that they identify and characterise direct and indirect effects of different variables. A direct

effect of an independent variable  $X$  onto a dependent variable  $Z$  is given by a linear regression/dependence:

$$Z = KX,$$

Where  $K$  is the coefficient for the direct effect, whose value is equal to the variation of  $Z$  where  $X$  is varied by one unit.

At the same time, if a variable  $X$  has a direct impact on  $Y$  ( $Y = K_1X$ ), and  $Y$  has a direct impact on  $Z$  ( $Z = K_2Y$ ), it is said that the variable  $X$  has an indirect effect on  $Z$  through the mediating variable  $Y$ :

$$Z = K_2Y = K_2 (K_1X) = K_1K_2X = K_{12}X; \quad \text{where} \quad K_{12} = K_1K_2.$$

Here,  $K_{12} = K_1K_2$  is the coefficient for the indirect effect of  $X$  on  $Z$ , which is equal to the variation of  $Z$  where  $X$  is varied by one unit.

All the numerical variables in the database, except for Year and Employee Number, were also logarithmically transformed to approximate normal distributions, which was necessary to improve applicability of the developed model.

# **Chapter 5. EGDC Analysis and Summary**

## **Measures**

This Chapter presents and discusses the first set of the major outcomes of this research, including the results of the descriptive statistical analysis of the available performance data for 30 different EGDCs, cluster analysis, the associated identifications of distinct groups of companies with particular characteristics and performance features, and the subsequent statistical comparisons between the identified groups (categories or clusters) of EGDCs. Explanations and interpretations of the obtained results and findings will also be undertaken based on the available information about the significant environmental factors, as well as local and federal government and legal regulatory frameworks associated with the performance of EGDCs in Australia.

### **5.1 Clustering/Classification of EGDCs**

The first step in the developed analysis of the available data on performance characteristics of 30 different EGDCs operating primarily in Australia (Appendix 1) will involve cluster analysis to reasonably identify distinct groups of companies with particular performance characteristics. The initial characterisation of the companies included in the database was conducted based on cluster analyses that were expected to identify groups of companies with similar performance characteristics. This was essential for a sensible evidence-based sub-division of the available companies into different categories (clusters) with their subsequent detailed statistical analysis and comparison, including the identification of characteristic features (determined by the cluster characteristics) and development of

specific recommendations to the individual companies, electricity generation/distribution industry, and government regulating authorities.

To ensure sufficient rigour and validity of the conducted identification of clusters of the companies, three different types of cluster analysis were used to compare, validate, and optimise the obtained outcomes and EGDC categories for their subsequent statistical analysis and modelling. As the first step towards classifying EGDCs in Australia, we used the principal component analysis (PCA). PCA is an exploratory statistical approach that can be used to construct reasonable clusters (categories) of measurement outcomes – in our case, EGDCs.

The outcomes of this research and the adopted classification/categorisation of EGDCs will be useful for the decision-making bodies at the government and private company levels to ensure sustainable managerial and government support, including through optimal legislative and regulatory frameworks, for the electricity generation/supply industry on the basis of the successful development of the involved EGDCs belonging to different clusters.

### **5.1.1 Principal Component Analysis (PCA)**

The statistical analyses and modelling within this research were significantly aimed at the identification of the major trends and performance characteristics of the considered 30 EGDCs (Appendix 1), which are expected to have a significant impact on the decision-making process and management of these EGDCs at the company and government levels to ensure rapid and sustainable development of the electricity generation/distribution industry in Australia under the changing environmental, legislative and business conditions. The created database (Appendix 1) contained three different types of EGDCs: electricity generation companies, electricity distribution companies, and electricity generation and distribution companies. It is, therefore, possible to expect that these types of business activities could be

the criteria for grouping of EGDCs into three groups with presumably distinct characteristics. However, this intuitive grouping should be confirmed or rejected by rigorous statistical means, one of which is based on PCA (Rabe-Hesketh and Everitt, 2007). Thus, the cluster analysis is expected to determine if type of business activities undertaken by a company is characteristic in determining this company's performance and the required management approaches, or other criteria should also be involved to ensure accurate and appropriate management and decision-making. To the best of our knowledge, this type of analysis has not been used previously in the literature.

Each EGDC is characterised by a set of performance variables available from the company reports, websites, and other available company and government sources (Appendix 1). However, as was explained in Chapter 4, it is quite difficult to directly evaluate these variables and properly understand which of them are particularly important for the characterisation of the companies and their mutual commonalities and/or differences. Therefore, PCA is used to identify similar EGDCs in a quantitative way to ensure the statistical rigor of the EGDC classification (Section 4.2.1).

In accordance with the PCA procedure described in Section 4.2.1 (see also Gorsuch, 1983; Rabe-Hesketh and Everitt, 2007), we apply PCA to the 7 original observed variables (Appendix 1): Revenue, Output, Cost of Sales, EBITDA, PP&E, Total Costs of Employees, and Employee Numbers. As a result, 7 principal components (linear combinations of the original variables) were obtained, including the coefficients (loadings) with which the original variables appear in these linear combinations. Using the Kaiser criterion (Kaiser and Rice, 1974; Gorsuch, 1983; Stevens, 2002; Rabe-Hesketh and Everitt, 2007), we retain only two principal components, PC1 and PC2, for which the eigenvalues are greater or equal to 1 (Table 5.1). The different levels of shading in Table 5.1 indicate different levels of contribution of the corresponding original variables (left column) to the identified two

principal components. In this way, Table 5.1 identifies all the original variables having significant contributions to each of the retained 2 principal components, as well as the corresponding loadings.

The second principal component (PC2) hardly depends on Cost of Sale and EBITDA, with PP&E and Output being the largest contributors (Table 5.1). It is also interesting that PC2 contains three original variables entering the corresponding linear combination with negative signs, namely, Total Cost of Employees, Employee Number, and Revenue. As a result, it could be said that PC2 is a new variable reflecting the difference between the material things produced or owned by the EGDC (produced electricity output and assets involved in electricity production) and the things associated with the cash flow combined with the available workforce (Table 5.1).

<b>Variable</b>	<b>PC1</b>	<b>PC2</b>
Revenue	0.4483	– 0.1855
Output	0.2735	0.5912
Cost of Sale	0.3384	0.0037
EBITDA	0.4244	0.0653
PP&E	0.2168	0.6638
Total Cost of Employees	0.4215	– 0.3328
Employee Number	0.4527	– 0.2456
	<b>61.7%</b>	<b>15.7%</b>

**Table 5.1.** The first two principal components PC1 and PC2 satisfying the Kaiser criterion. No shading indicates the factor loadings exceeding the conventional threshold value of 0.3 for the corresponding variables (left column) to be considered as major factor contributors (Gorsuch, 1983; Stevens, 2002). Light shading indicates the factor loadings that correspond to variables that produce notably smaller but still significant contributions to the respective factors. Dark shading indicates variables that have negligible impact on the

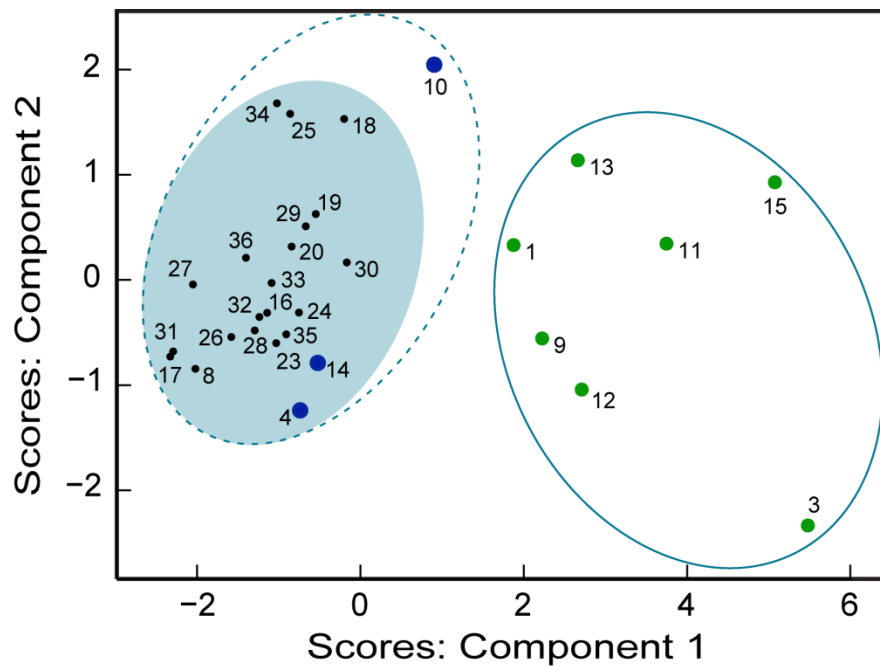
corresponding factors. The percentages in the bottom row of the table show the respective percentages of the total variance explained by the corresponding principal component.

The indicated percentages of the total variance explained/extracted by PC1 and PC2 (Table 5.1) demonstrate the rapid decrease of the relative importance of the obtained principal components, which enables us to retain only the first two of them (PC1 and PC2 – Table 5.1) for the proposed EGDC characterisation. The combined contribution of all the remaining 5 principal components is only about 22.6%, which makes each of them much less important for EGDC characterisation, compared to PC1 and PC2. This is the mathematical ground for discarding these 5 principal components from the analysis, which is one of the major advantages of PCA – significant reduction of the total number of variables significantly characterising the considered entities (EGDCs).

As a result, the constructed factors PC1 and PC2 represent the two new variables describing the considered EGDCs, which are mutually independent (i.e., they do not correlate with each other) and there are only two of them instead of the 7 original variables (Appendix 1). This is a major simplification of the problem, allowing us to conduct sensible classification of the considered EGDCs based on just two principal components (Table 5.1). In addition, because now we have only two major independent variables (PC1 and PC2) characterising the performance and features of EGDCs, this characterisation can be done using graphical means (Rabe-Hesketh and Everitt, 2007).

Principal components are numerical variables characterised by their scores that are calculated from the original variables (Appendix 1) and the derived linear combinations of those original variables determining the principal components (Everitt, 1994; Rabe-Hesketh and Everitt, 2007). If there are only two principal components with the major contributions to the data variance (as in our case of EGDC characterisation), these two principal components

can be used to construct a single scatter-plot with PC2 on the vertical axis and PC1 on the horizontal axis (Fig. 5.1). Different companies having different values of PC1 and PC2 are then represented by dots on this scatter-plot (Fig. 5.1). The more similar any two EGDCs are, the closer will their corresponding points be positioned on the scatter-plot (because the characterising them variables PC1 and PC2 will be similar). Therefore, the distance between any two points on the scatter-plot (Fig. 5.1) can be considered as a measure of difference between the corresponding two EGDCs (Everitt, 1994; Rabe-Hesketh and Everitt, 2007). This provides us with a useful tool to reliably identify clusters of similar EGDCs, i.e., those whose corresponding points are clustered in Fig. 5.1.



**Figure 5.1.** Note: The outcomes of PCA and cluster analyses to identify distinct groups (clusters) of the electricity EGDCs. The distances between the points indicates the existing differences between EGDCs based on the conducted PCA – the smaller the distance between any two points, the more similar the corresponding companies are in terms of their performance characteristics. The ellipses identify the three different clusters of the considered EGDCs obtained from the Average Linkage and k-means clustering approaches (Rabe-Hesketh and Everitt, 2007). The final clustering: Cluster 1 – solid ellipse; Cluster 2 – dashed ellipse.



In particular, it can be seen that there are two distinct clusters of points: those that are black and blue, and those that are green in Fig. 5.1. Importantly, the black points correspond to the ‘generation’ (G) and ‘generation+distribution’ (GD) EGDCs, whereas the green dots correspond to just ‘distribution’ (D) EGDCs (see also Appendix 1). This suggests that the originally intuitively proposed clustering of EGDCs on the basis of their type of activity appears to be reasonable (at least to the extent that G EGDCs and GD EGDCs are significantly different from D EGDCs).

### **5.1.2 Cluster Analysis**

There are three EGDCs (see the blue dots in Fig. 5.1) that are D chains, but they appear to group with G EGDCs. This indicates that further analysis is required to understand these outcomes and to ensure reliable evidence-based clustering (suitable classification or categorisation) of EGDCs.

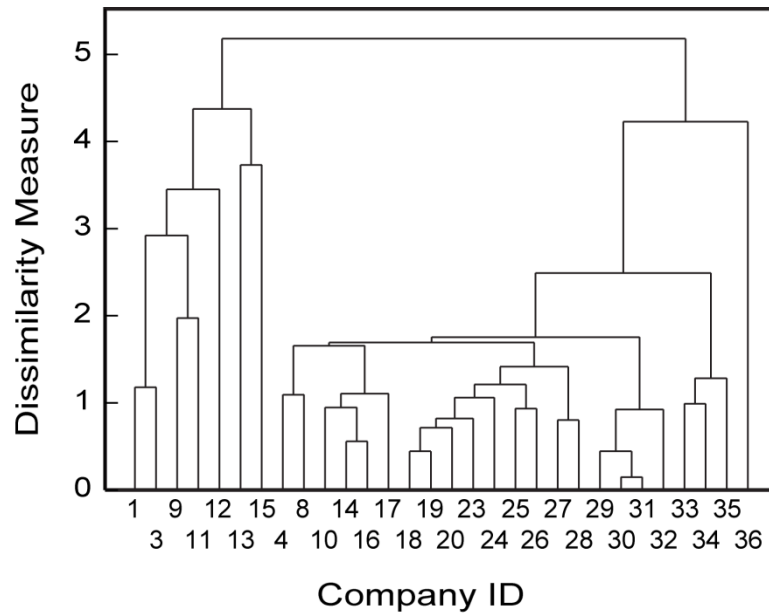
This further considerations based on cluster analysis had to be used to establish rigorous (statistically-based) ways of grouping EGDCs, rather than relying on merely visual perception of mutual positioning for the points in Fig. 5.1. Cluster analysis is a type of (largely) exploratory data analysis techniques that seek to determine groups or clusters in the data. Cluster analysis methods are typically used to generate hypotheses rather than to test and develop them (Rabe-Hesketh and Everitt, 2007). Therefore, clustering techniques are typically called ‘exploratory’. In our case, we use these techniques to generate some reasonable clusters of EGDCs and study their properties using the summary statistics methods and measures (see below), which will then be tested and rigorously confirmed through the statistical modelling (Chapter 6).

Therefore, as the second step in the conducted attempts to establish clustering of EGDCs in Australia was based on the k-means clustering algorithm (Calinski and Harabasz,

1974; Rabe-Hesketh and Everitt, 2007). This approach suggested 2 different clusters of EGDCs. The first cluster included all black dots in Fig. 5.1, plus the blue dots with the ID numbers 4 and 14 (see the green shaded ellipse in Fig. 5.1). The second suggested cluster included all green dots in Fig. 5.1, plus the blue point with the ID number 10. This second cluster did not agree well with the described PCA, as the distances between point 10 in Fig. 5.1 and the majority of the green points (particularly, point 3) are large, which is indicative of the substantial differences between EGDC 10 and many of EGDCs in the cluster with the green dots.

Therefore, the third clustering approach called Average Linkage method (Rabe-Hesketh and Everitt, 2007) was used to clarify the situation with clustering (Fig. 5.1). The dendrogram shown in Fig. 5.2 illustrates this Average Linkage method showing the proposed clustering of EGDCs. Further, using the Duda and Hart index (Duda and Hart, 1973) that should be maximal in the event of correct cluster choice, and the trial and error method to maximise this index, we derive that the Average Linkage method also suggests 2 different clusters. The first cluster includes all green dots in Fig. 5.1 (the solid ellipse – Cluster 1), whereas the second cluster includes all black and blue dots in Fig. 5.1 (the dotted ellipse – Cluster 2). Because this sub-division appeared to us most reasonable and most consistent with all three approaches (PCA, k-means method, and Average Linkage method), it was decided to assume this final cluster subdivision of the considered electricity EGDCs in Australia.

Based on this, we had to consider at least two different categories of electricity EGDCs, corresponding to describe cluster sub-division. However, for the sake of not losing any information in the subsequent summary statistical analysis and, particularly, in the statistical modelling involving different categories of EGDCs, it was decided to use four different categories of the considered EGDCs, based on their clustering and type of activities:



**Figure 5.2.** The dendrogram obtained from the Average Linkage clustering method for the considered 30 EGDCs.

Category 0 (base category): The thirteen G EGDCs from Cluster 2 (Fig. 5.1 and Appendix 1):

Category 1: The seven GD EGDCs from Cluster 2 (Fig. 5.1 and Appendix 1);

Category 2: The three D EGDCs ( $D_3$ ) from Cluster 2 (blue dots in Fig. 5.1); and

Category 3: All seven D EGDCs from Cluster 1 (green dots with solid ellipse in Fig. 5.1).

As explained above, similar to the developed cluster analysis, the adopted categorisation (with the four different categories) was designed to simplify characterisation and comparison of EGDCs with other similar or dissimilar EGDCs. In other words, the adopted categorisation (classification) of EGDCs on the Australian electricity generation/supply market will provide CEOs and company management with an additional useful tool that will enable them to easily classify their EGDC and follow (or at least take

into account) the predetermined trends for their category, as well as the specific predictions related to their particular company (see Section 5.3 below for more detail).

In addition, the determined clusters and categories of different electricity EGDCs on the Australian market represent the fundamental new knowledge in the electricity generation/supply industry. The detailed analysis of any differences between the adopted EGDC categories will be instrumental and helpful for the proper understanding of the major general and fundamental trends, problems and issues on the Australian electricity supply market. For example, as will be shown below, EGDCs from different clusters and/or categories are likely to require different management approaches and external stimuluses.

## **5.2 Summary Statistics for EGDCs**

The described clusters and categories of EGDCs in Australia enabled reasonable comparisons between the different groups of similar EGDCs with regard to their performance and operation/activity types. The adopted categorisation of EGDCs also allowed the determination of the average values of the considered variables for each EGDC category (Table. 5.2). These category-average values make greater practical sense and importance than averaging over the whole industry, as they provide useful average information about the four different characteristic types of EGDCs on the Australian market, enabling their separate analysis and comparisons.

In particular, it can be seen that an average G EGDC from category 0 (forming cluster 2 – Fig. 5.1) is a relatively small company with relatively small employee costs (about 2-3 times smaller than that for an average D EGDC – see categories 2 and 3 in Table 5.2). Category 3 includes particularly large D EGDCs, having the average of ~ 4200 employees, compared to the average of ~ 1100 employees for the other D<sub>3</sub> EGDCs from category 2. These D<sub>3</sub> companies (category 2) stand distinctly separately from the rest of the (larger) D

EGDCs (cluster 1 – Fig. 5.1), and have significantly smaller PP&E, revenue and EBITDA, but not the output (Table 5.2). The likely reason for the D<sub>3</sub> EGDCs to be significantly different from the D EGDCs (cluster 1) is probably related to their smaller size (as well as the managerial and market differences related to their significantly smaller size). This further demonstrates the reasonable grounds behind the adopted sub-dividing the considered companies into the 4 different categories defined in the end of the previous section.

Category	Mean Values						
	Output, GWh	Revenue, ×\$10 <sup>8</sup>	EBITDA ×\$10 <sup>8</sup>	Cost of Sales, ×\$10 <sup>8</sup>	PP&E, ×\$10 <sup>8</sup>	Employee Cost, ×\$10 <sup>8</sup>	Number of Employees
<b>0 (G)</b>	7135.3	6.9	2.7	0.558	32	0.511	512.4
<b>1 (GD)</b>	7565.8	6.3	3.0	0.501	32	0.637	501.9
<b>2 (D<sub>3</sub>)</b>	20266.3	8.6	2.4	2.696	26	1.159	1120.3
<b>3 (D)</b>	19212.5	21	8.1	5.345	54	2.811	4204.5

**Table 5.2.** Mean values of the considered variables for each of the four EGDC categories over the 6 considered years between 2007 and 2012.

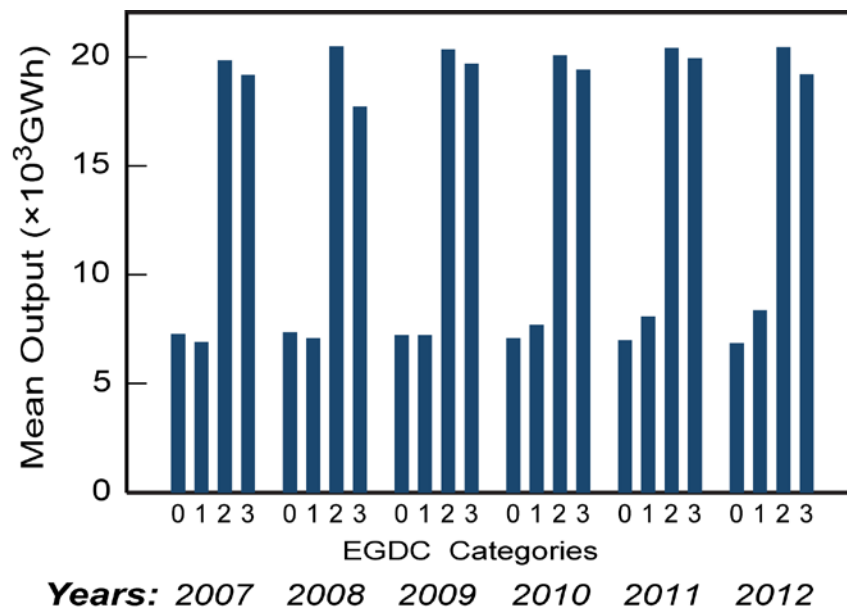
The ratios of the mean values of the considered variables are of particular importance, as they provide information about the efficiency with which EGDC in utilising its resources to produce the output, and/or illustrate the essential performance parameters relative to other such parameters (Table 5.3). The most important of these ratios are the *Labour Productivity* =  $\frac{Output}{EC}$  and *Capital Productivity* =  $\frac{Output}{PP \& E}$  (Table 5.3), as they directly reflect the performance efficiency of EGDC.

The figures below in this section present further graphical illustrations of the differences and similarities between the four identified categories of EGDCs with regard to the considered variables (Table 5.2) and their corresponding ratios (Table 5.3).

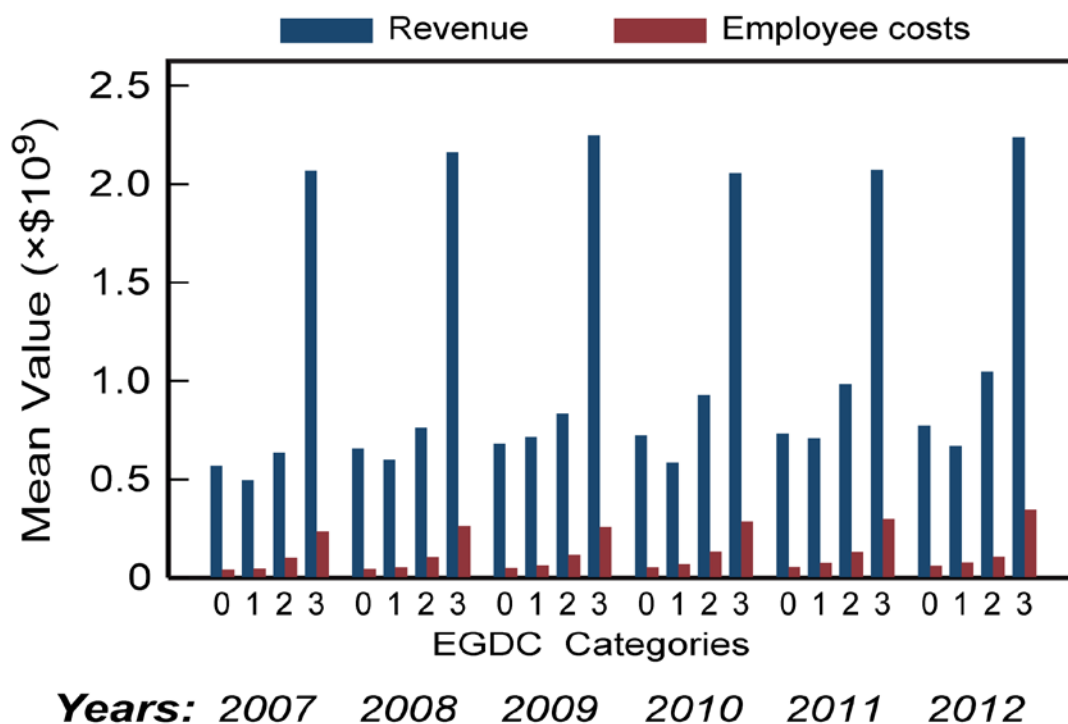
Category	Mean Ratios of Variables			
	Output/ Revenue	Output/ Employee Number	Output/ Employee Cost	Output/ PP&E
<b>0 (G)</b>	$1.09 \times 10^{-5}$	13.2	$1.6 \times 10^{-4}$	$2.81 \times 10^{-6}$
<b>1 (GD)</b>	$1.43 \times 10^{-5}$	14.5	$1.2 \times 10^{-4}$	$3.16 \times 10^{-6}$
<b>2 (D<sub>3</sub>)</b>	$2.68 \times 10^{-5}$	20.8	$2.9 \times 10^{-4}$	$6.79 \times 10^{-6}$
<b>3 (D)</b>	$0.93 \times 10^{-5}$	4.5	$0.71 \times 10^{-4}$	$5.76 \times 10^{-4}$ ( $2.65 \times 10^{-6}$ )

Category	Mean Ratios of Variables		
	Cost of Sale/ Revenue	Cost of Sale/ Output	Cost of Sale/ Employee Number
<b>0 (G)</b>	$1.23 \times 10^{-1}$	$14.1 \times 10^3$	$127.3 \times 10^3$
<b>1 (GD)</b>	$1.06 \times 10^{-1}$	$11.8 \times 10^3$	$97.0 \times 10^3$
<b>2 (D<sub>3</sub>)</b>	$3.46 \times 10^{-1}$	$38.4 \times 10^3$	$255.7 \times 10^3$
<b>3 (D)</b>	$3.23 \times 10^{-1}$	$36.6 \times 10^3$	$150.4 \times 10^3$

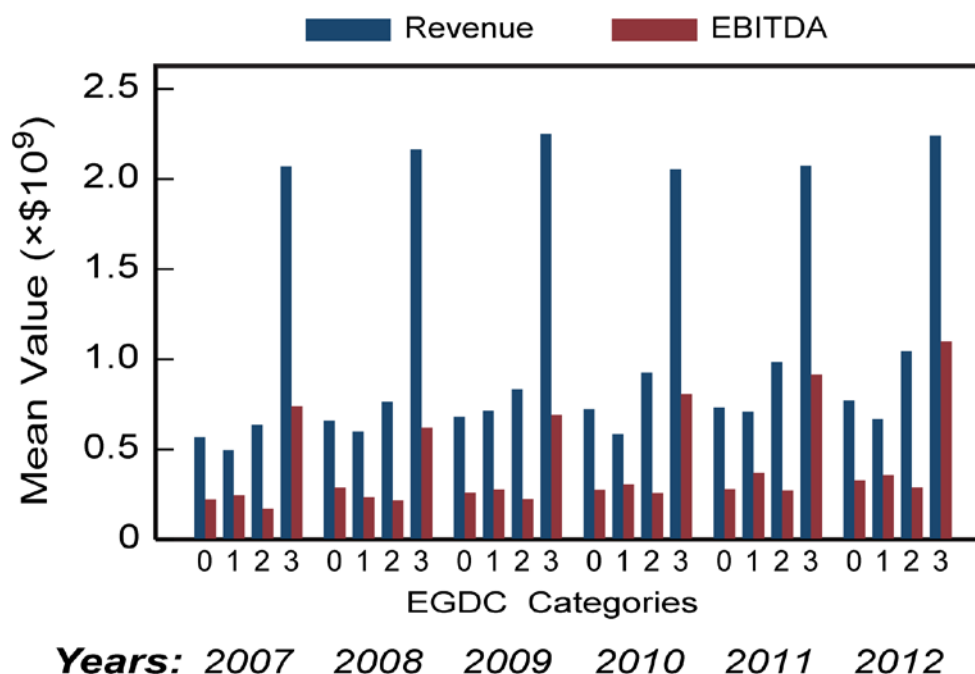
**Table 5.3.** Mean ratios of the considered variables for each of the four EGDC categories over the 6 considered years between 2007 and 2012. The value in brackets was calculated without the Sydney County Council (Ausgrid) company.



**Figure 5.3.** Mean values of the electricity output for the average EGDCs from the four EGDC categories (0, 1, 2, and 3) in the years between 2007 and 2012.



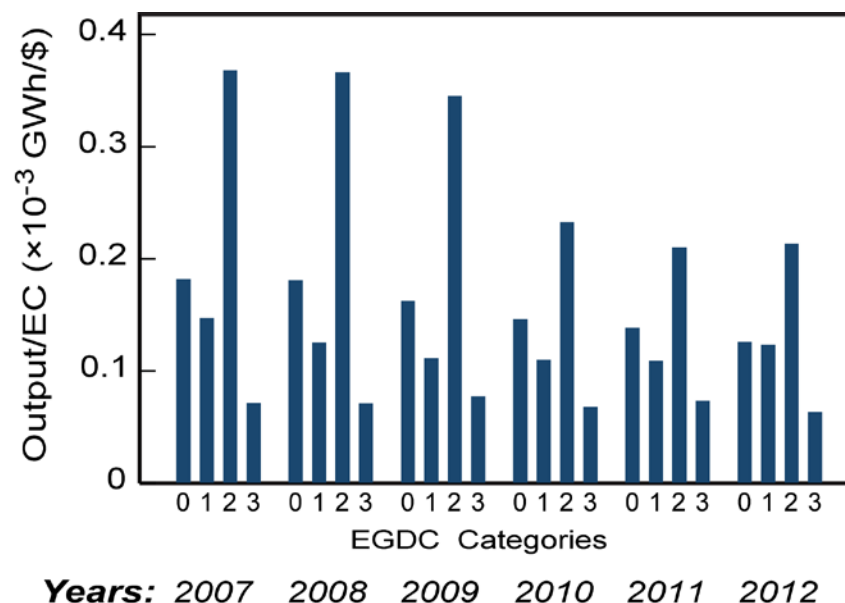
**Figure 5.4.** Mean values of the revenue and employee costs for the average EGDCs from the four categories (0, 1, 2, and 3) in the years between 2007 and 2012.



**Figure 5.5.** Note: Mean values of the revenue and EBITDA for the average EGDCs from the four categories (0, 1, 2, and 3) in the years between 2007 and 2012.

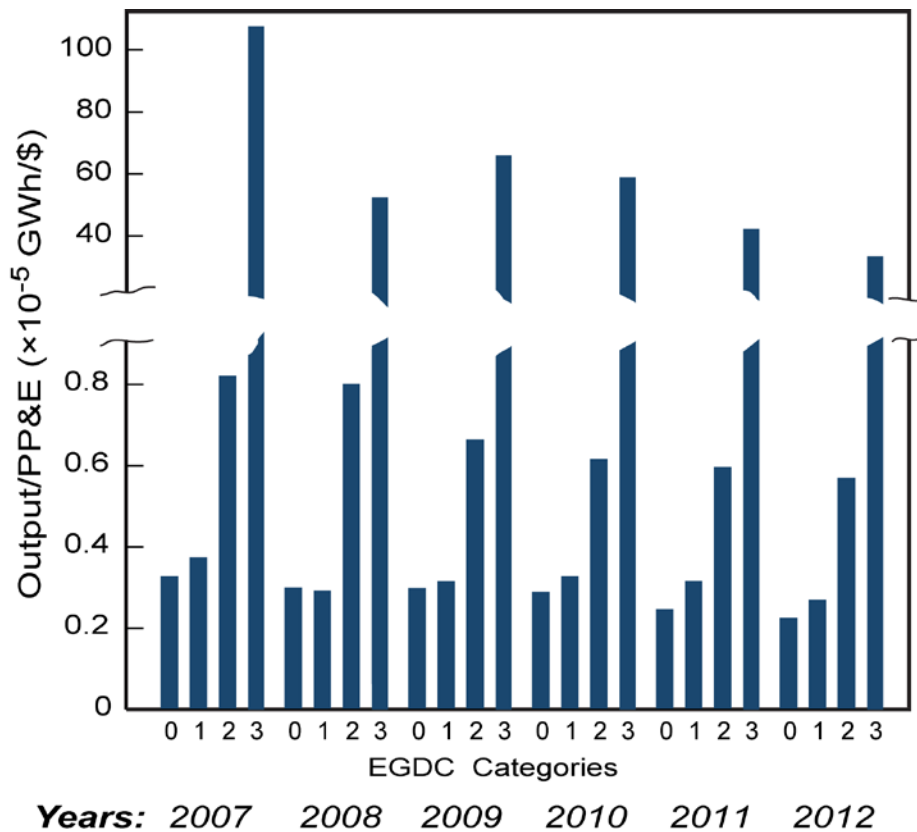
It can be seen that the variations of the mean output over the considered six years was rather limited for all four categories of EGDCs (Fig. 5.3). It can thus be concluded that the electricity generation output in Australia was quite stable on average over the analysed period. The average employee costs were also stable with only slight (and rather expected) trend towards increased costs for all four EGDC categories (Fig. 5.4). At the same time, while the average revenue for category 3 (large D EGDCs from cluster 1 – Fig. 5.1) also remained rather stable (with a slight decrease in 2010 and 2011 – Figs. 5.4 and 5.5), EBITDA increased notably for all four EGDCs categories (Fig. 5.5). This indication of relative financial health of the electricity supply industry in Australia.

Note, however, that these trends appear only from the consideration of the average values over several years with no any adjustments to any other variables or factors. Therefore, we do not yet know the causes for any of these trends or how variables influence each other to produce the indicated trends. These questions require detailed statistical modelling involving all the considered variables (see Chapter 6).



**Figure 5.6.** Note: Mean values of the ratio of the output to employee cost (labour productivity) for the average EGDCs from the four categories (0, 1, 2, and 3) in the years 2007 – 2012.





**Figure 5.7.** Note: Mean values of the ratio of the output to PP&E (capital productivity) for the average EGDCs from the four categories (0, 1, 2, and 3) in the years 2007–2012.

Figs. 5.6 and 5.7 show the summary statistics for the two most important parameters illustrating the EGDC performance and efficiency: labour productivity and capital productivity, respectively. In particular, it can be seen that there is a significant trend for EGDCs from categories 0 (G EGDCs) and from category 2 (the three smaller D<sub>3</sub> EGDCs grouping with the G EGDCs – Fig. 5.1) towards significant reduction of labour productivity (Fig. 5.6). Although this trend deserves attention due to its potential negative consequences, the fact that these EGDC categories are characterised by significantly higher average levels of labour productivity than those from the other two categories 1 and 3 significantly mitigates any immediate concerns about undesirable impacts of this negative trend for labour productivity.

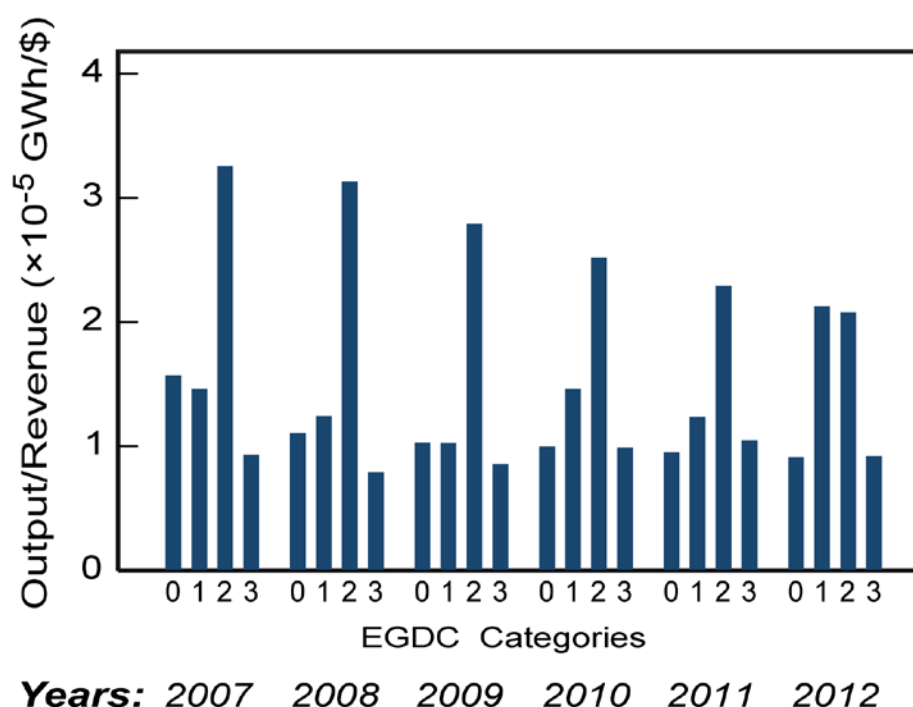
Somewhat similar situation occurs for the capital productivity (Fig. 5.7). In this case, the reduction trend is characteristic for all four categories of EGDCs, though it is most pronounced for categories 2 and 3 (D and D<sub>3</sub> EGDCs) (Fig. 5.7), and least pronounced for categories 0 and 1 (G and GD EGDCs). This suggests that mainly the electricity distribution market is affected by this negative trend. Taking into account the previously indicated lack of any significant trends in the average electricity output (Fig. 5.3), the indicated trend towards reducing capital productivity is likely to be related to increasing average PP&E.

We also note a very large (~ 2 orders of magnitude) difference between the average capital productivity for category 3 and all other categories (Fig. 5.7). This difference is rather a mathematical artefact related to just one company: Sydney County Council (Ausgrid) – Appendix 1. This company has PP&E that is about 2-3 orders of magnitude lower than PP&E for other D companies (Appendix 1), which causes a major increase of the average capital productivity values for category 3 in Fig. 5.7. This suggests that the consideration of Sydney County Council (Ausgrid) together with the other D EGDCs in category 3 might not be fully justified due to these major differences in the EGDC and supply chain structures, capital and asserts. Nevertheless, at this stage, it was decided to keep Sydney County Council (Ausgrid) EGDC in the considered database (Appendix 1) and in category 3 on the ground that, according to the conducted tests, its removal does not introduce significant changes to the obtained model outcomes and findings. For completeness of the presentation, the average values of capital productivity for category 3 in the absence of the Sydney County Council (Ausgrid) company were  $3.17 \times 10^{-6}$  GWh/\$ in 2007;  $3.09 \times 10^{-6}$  GWh/\$ in 2008;  $2.84 \times 10^{-6}$  GWh/\$ in 2009;  $2.40 \times 10^{-6}$  GWh/\$ in 2010;  $2.49 \times 10^{-6}$  GWh/\$ in 2011; and  $2.17 \times 10^{-6}$  GWh/\$ in 2012 (see also Table 5.2).

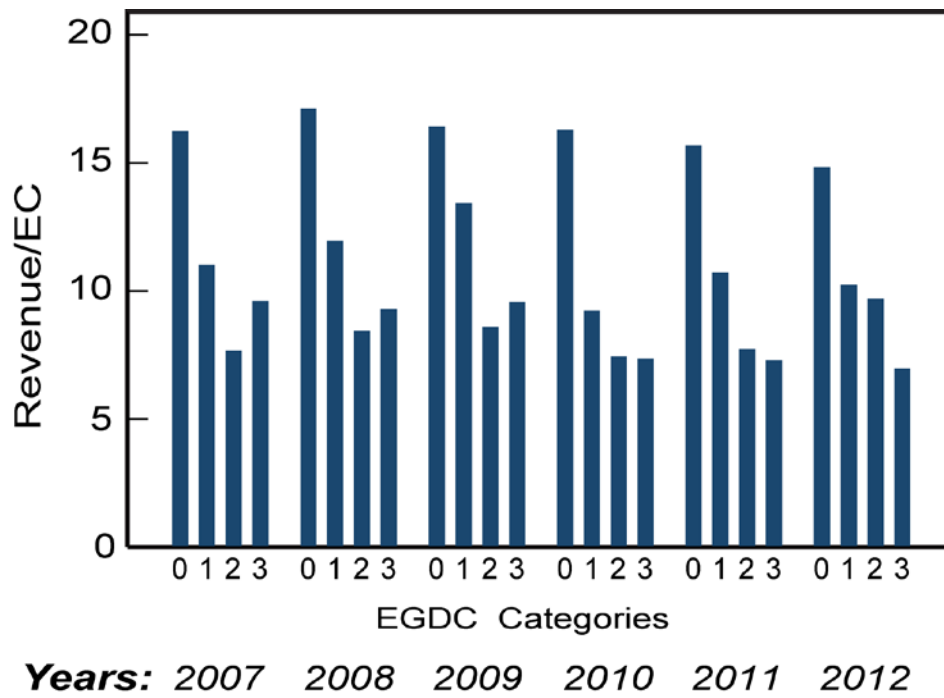
Interestingly, the distribution EGDCs (apart from the smaller D<sub>3</sub> EGDCs grouping with the G companies – Fig. 5.1) are characterised by significantly lower average labour

productivity (Fig. 5.6), while the D<sub>3</sub> chains have the highest labour productivity. On the contrary, capital productivity in D EGDCs is significantly higher than in G or GD EGDCs (Fig. 5.7).

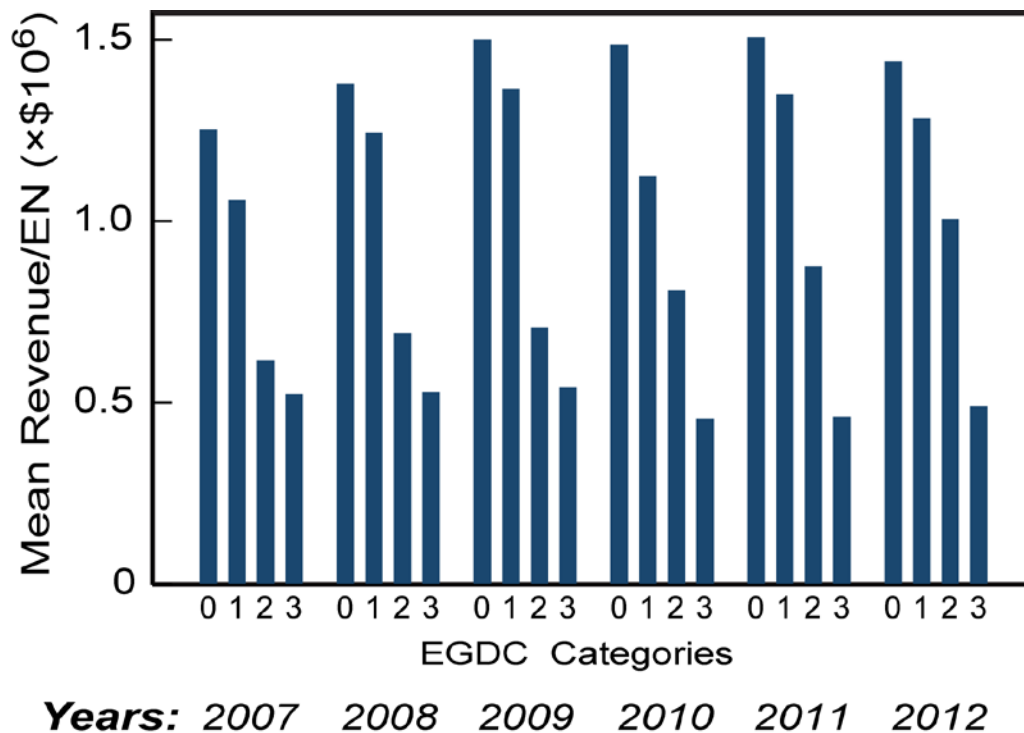
The summary statistics for the ratio of output on revenue does not reveal any noticeable trends for the majority of D EGDCs (category 3) – Fig. 5.8. At the same time, there is notable trend towards reducing this ratio for categories 0 (G EGDCs) and category 2 (smaller D<sub>3</sub> EGDCs grouping with the G chains) – Fig. 5.8. This trend is an indication of increasing revenue for these companies on the background of approximately constant average output (Fig. 5.3). Category 1 consisting of GD EGDCs demonstrate mixed trends with increasing the output to revenue ratio during the last 4 years of observation (Fig. 5.8). This is likely to be largely caused by the increased output during the same years (Fig. 5.3).



**Figure 5.8.** Notes: Mean values of the ratio of the output to revenue for the average EGDCs from the four categories (0, 1, 2, and 3) in the years between 2007 and 2012.

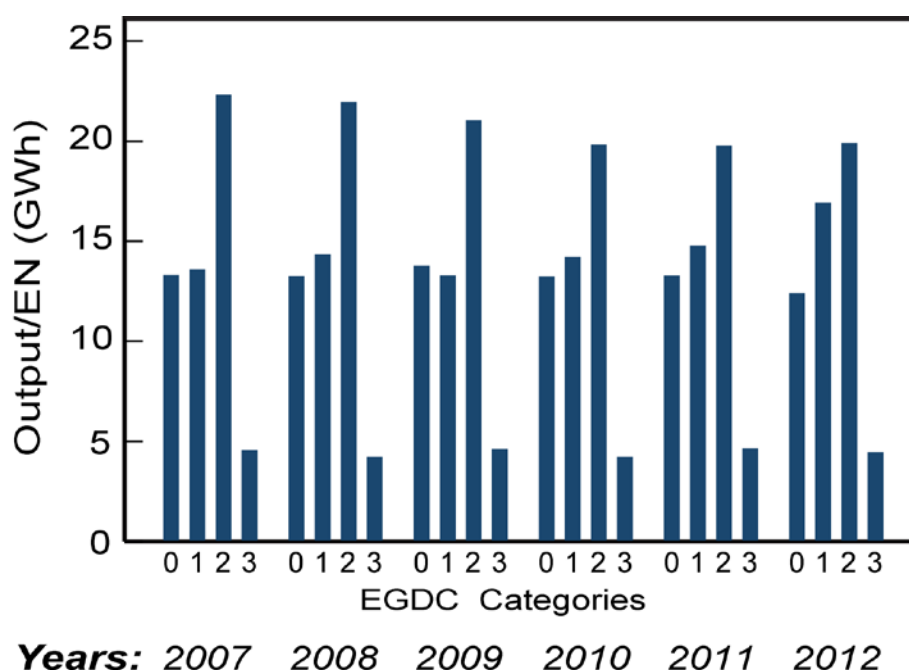


**Figure 5.9.** Note: Mean values of the ratio of the revenue to employee cost for the average EGDCs from the four categories (0, 1, 2, and 3) in the years between 2007 and 2012.

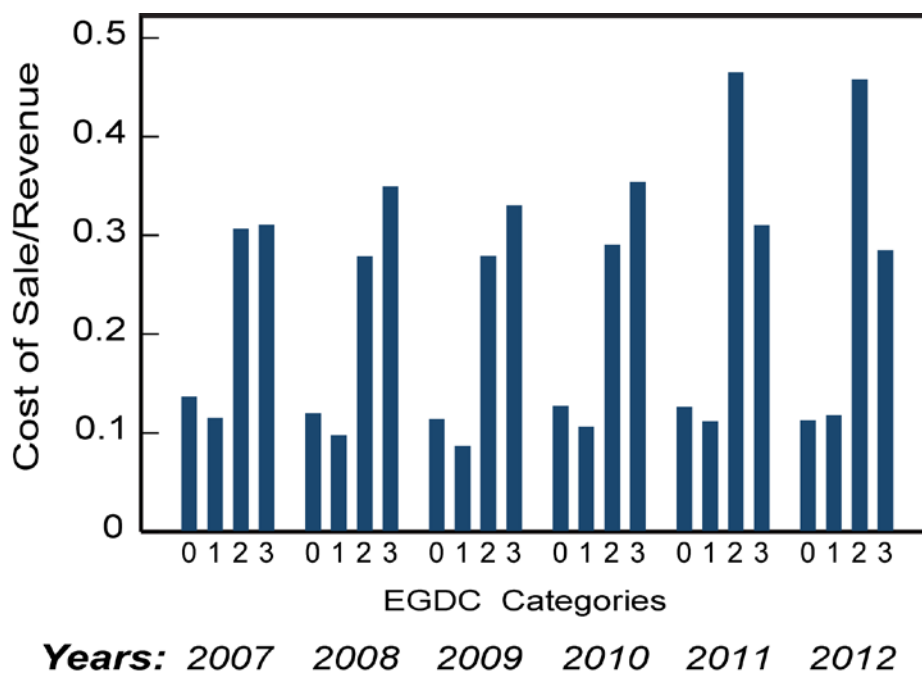


**Figure 5.10.** Note: Mean values of the revenue per employee for the average EGDCs from the four categories (0, 1, 2, and 3) in the years between 2007 and 2012.

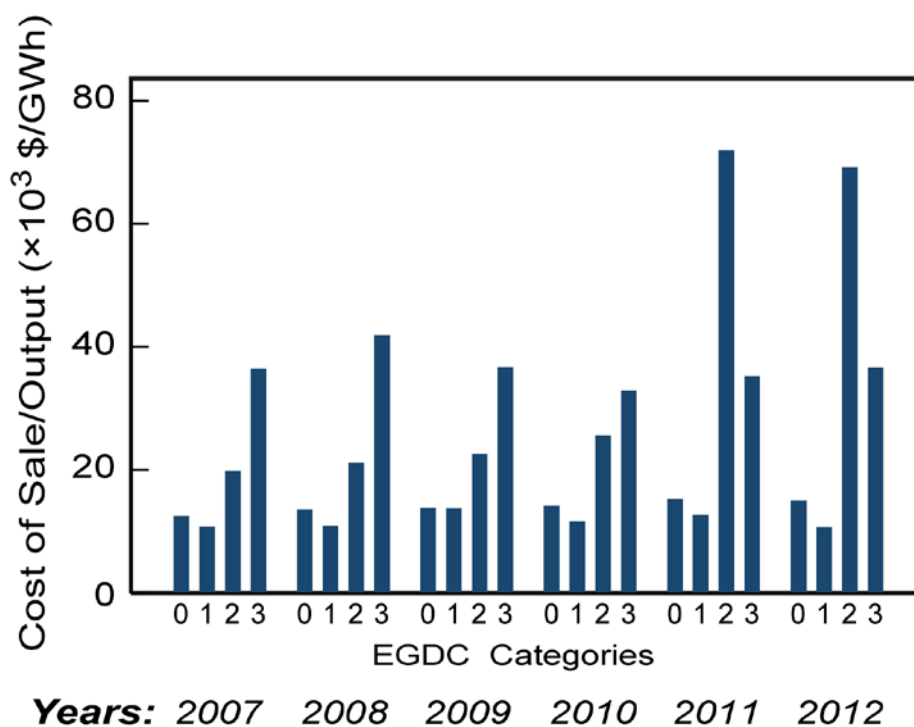
There are few consistent trends for the ratios of revenue of employee costs (though categories 0 and 1 are characterised by larger average values of this ratio – Fig. 5.9) and output on employee numbers (though category 3 is characterised by smaller values of this ratio – Fig. 5.11). Interestingly, there is a major difference between the  $D_3$  and D EGDCs from categories 2 and 3, with the smaller  $D_3$  companies having much larger ratio of output to employee number (Fig. 5.11), which could be related to lower efficiency of smaller  $D_3$  EGDCs. There is a notable trend towards increasing mean ratio of revenue on employee number over the observation period for categories 1 and 2 (Fig. 5.10), with categories 0 and 1 having larger values of this ratio. There are no clear trends over the observation period for the ratio of cost of sale on revenue, with the D and  $D_3$  companies having larger average values (Fig. 5.12). This last finding is likely to be linked to significantly more sophisticated, complex, and thus costly operational aspects and networks associated with the distribution of electricity to consumers, compared to its generation.



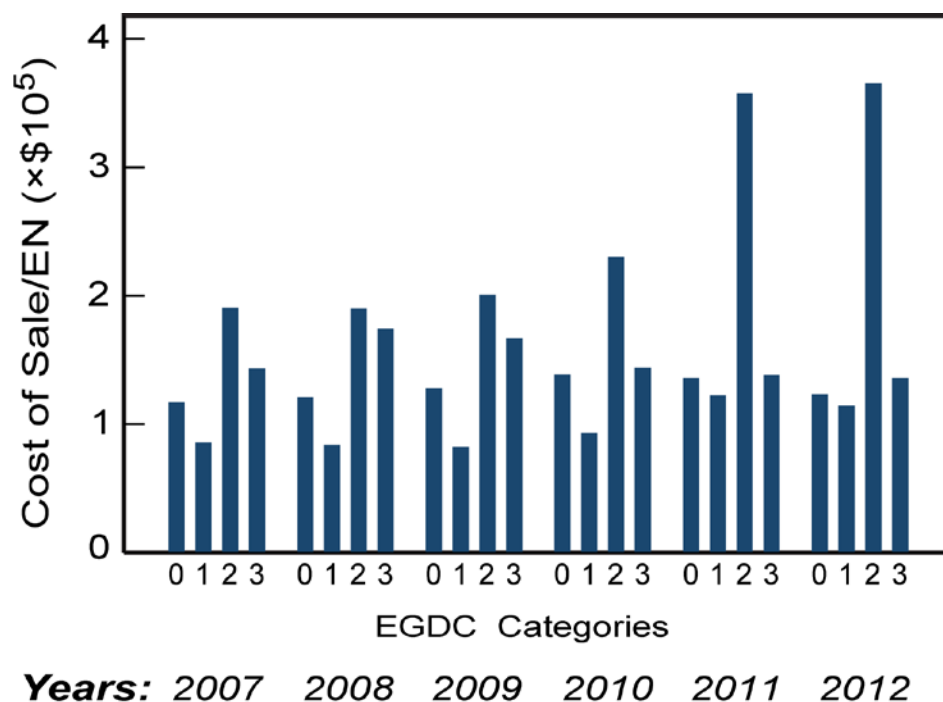
**Figure 5.11.** Note: Mean values of the output per one employee for the average EGDCs from the four categories (0, 1, 2, and 3) in the years between 2007 and 2012.



**Figure 5.12.** Note: Mean values of the ratio of the cost of sale on revenue for the average EGDCs from the four categories (0, 1, 2, and 3) in the years between 2007 and 2012.



**Figure 5.13.** Mean values of the ratio of the cost of sale on output for the average EGDCs from the four categories (0, 1, 2, and 3) in the years between 2007 and 2012.



**Figure 5.14.** Note: Mean values of the ratio of the cost of sale on employee number for the average EGDCs from the four categories (0, 1, 2, and 3) in the years between 2007 and 2012.

The ratio of cost of sales to output does not display any notable trends for the considered categories of EGDCs, except for the smaller D<sub>3</sub> EGDCs (blue dots in Fig. 5.1) in which case this ratio notably increases over the time of observation between 2007 and 2012 (Fig. 5.13). In addition, the D EGDCs are characterised by larger ratios of cost of sale to output (Fig. 5.13). As explained in the previous paragraph this is likely to be the consequence of more costly operations involving sophisticated and complex distribution networks for D and D<sub>3</sub> EGDCs (see also Table 5.2).

Similarly, the ratio of cost of sale on employee number also display a notable and rather consistent trend only for the smaller D<sub>3</sub> EGDCs (category 2 – Fig. 5.14). This trend is towards increasing this ratio over the period of observation between 2007 and 2012. The D and D<sub>3</sub> EGDCs again tend to have larger values of this ratio, which is again likely to be due higher operational cost of electricity distribution compared to its generation. However, this

tendency is not as obvious in Fig. 5.14 as in Fig. 5.13, which is probably due to larger numbers of employees required to properly service the distribution operations (see also Table 5.2). This finding and its proposed explanation are further corroborated by Fig. 5.10, which shows significantly smaller ratios of revenue to employee number for the D and D<sub>3</sub> EGDCs in comparison to G and GD EGDCs.

Note again that all the discussed trends for different performance variables and their ratios (including capital and labour productivities – Figs. 5.6 and 5.7) were obtained only from the consideration of the average values with no any adjustments to any other variables or factors. The proposed explanations are, therefore, only very preliminary considerations (based on rather superficial descriptive and visual perceptions of the presented summary graphs of average values), which still have to be confirmed by the detailed and rigorous statistical modelling (see Chapter 6) to rigorously identify and characterise any causes for the observed trends and their relationships with other variables.

An interesting and rather typical question for summary statistics is the determination of whether or not there is statistically significant difference between the considered categories of EGDCs (which were based on the outcomes of the conducted cluster analysis (Fig. 5.1) and type company business). Although categorisation could be made using different criteria, it is commonly expected that properly chosen categories should display statistically significant differences. If, for example, there is no statistically significant difference between the adopted categories, then the proposed categorisation may not be optimal or reasonable. On the contrary, if the adopted categories display statistically significant differences, such categorisation is reasonable and is likely to reflect the differences between the respective groups of EGDCs.

Because of the significantly not normal (non-Gaussian) distribution of the performance data the standard ANOVA test is not applicable for the evaluation of the



differences between the adopted four categories of EGDCs. Therefore, we used the Kruskal-Wallis equality-of-populations rank test that is applicable for non-Gaussian distributions of the variables (in our case, performance variables – Table 5.1 and Appendix 1).

<b>Variable</b>	<b><i>p</i>-value</b>
Output	< 0.0001
Revenue	< 0.0001
EBITDA	< 0.0001
Cost of Sale	< 0.0001
PP&E	< 0.0001
Employee Cost	< 0.0001
Employee Number	< 0.0001

**Table 5.4.** The outcomes of the Kruskal-Wallis test for comparison between the four adopted categories of EGDCs for each of the considered performance variables over the 6 years of observation.

<b>Variable</b>	<b><i>p</i>-value</b>
Output/Revenue	< 0.0001
Output/EN	< 0.0001
Output/One Employee Cost	< 0.0001
Output/All Employee Cost	0.055
Output/PP&E	< 0.0001
Cost of Sale/Revenue	< 0.0001
Cost of Sale/Output	< 0.0001
Cost of Sale/EN	0.0002

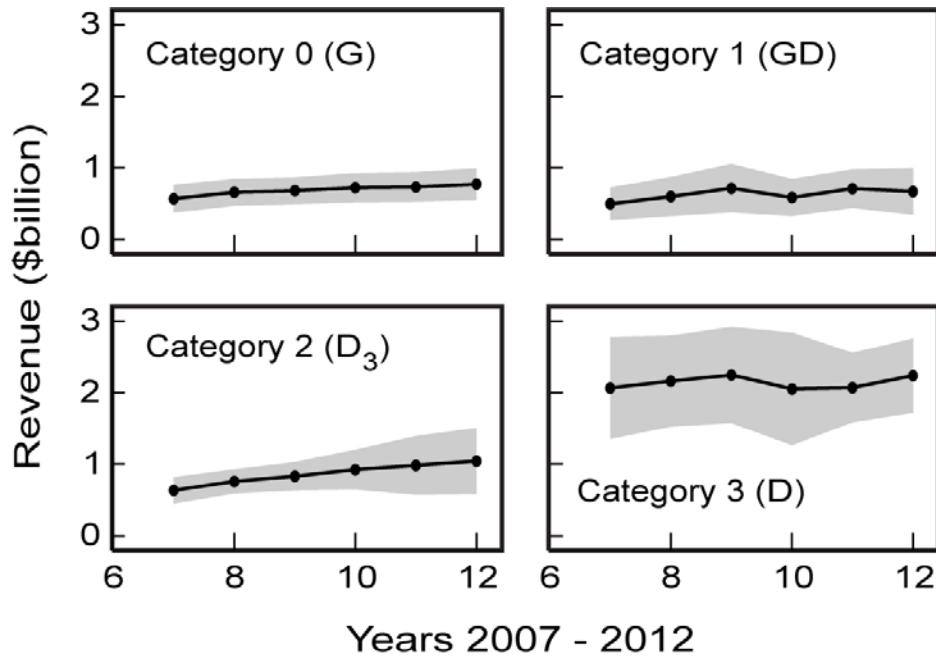
**Table 5.5.** The outcomes of the Kruskal-Wallis test for comparison between the four adopted categories of EGDCs for the ratios of the considered performance variables over the 6 years of observation.

Applying the Kruskal-Wallis test to compare the differences between the distributions of each of the performance variables and their ratios for the four adopted categories gives the *p*-values shown in Tables 5.4 and 5.5. The conventional threshold for statistical significance

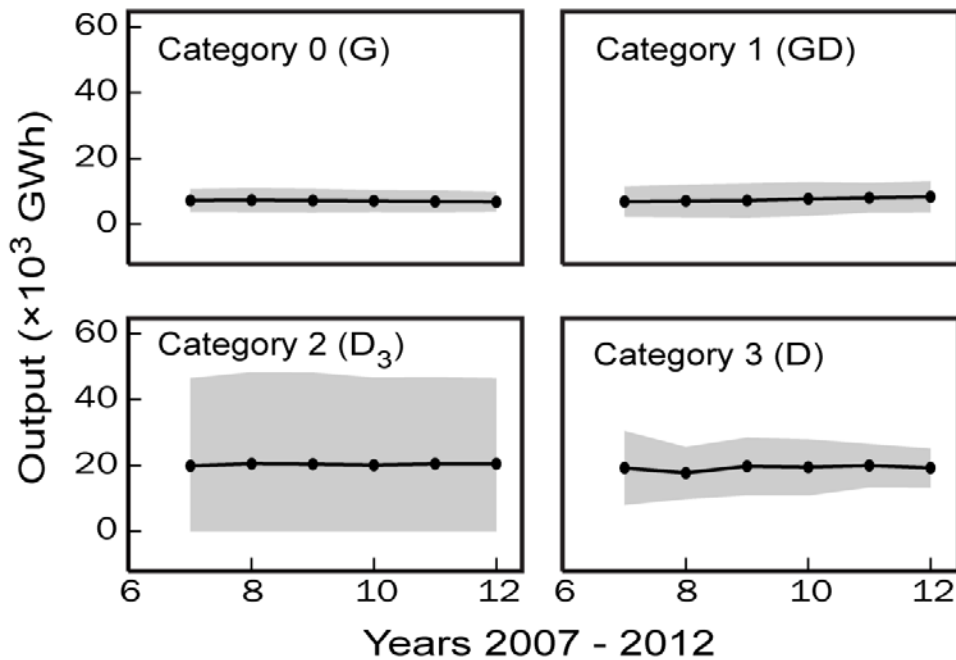
in this test is 0.05: if the obtained p-values are smaller than 0.05, the differences between the 4 categories are significant; if the obtained p-values are larger than 0.05, the differences between the 4 categories are not significant. As can be seen from Tables 5.4 and 5.5, almost all of the obtained p-values are much lower than the conventional significance limit of 0.05, which means that the differences between the 4 adopted categories are highly significant. The only exception is the ratio of output on employee cost that gives the p-value at the border of statistical significance (Table 5.5). Therefore, the adopted categorisation into four different categories is reasonable and statistically justified, as all the performance variables and their ratios are significantly different for these categories and their consideration/comparison is likely to reveal important features and trends in the Australian electricity supply market.

Finally, the dependences of the mean values of revenues and mean output for the average EGDCs from the four categories (0, 1, 2, and 3) on time in years between 2007 and 2012 are shown in Figs. 5.15 and 5.16. In particular, Fig. 5.16 corroborates the previous finding about the high level of stability of electricity output in the Australia market between 2007 and 2012 (see Fig. 5.3). There is no any clear trend for electricity output for any of the considered four categories, particularly where the calculated statistical errors (in the form of the 95% confidence intervals) are taken into account (Fig. 5.16). Although the dependence of revenue on years appears more distinct (e.g., for category 2 – Fig. 5.15), these dependences are not statistically significant when the corresponding errors are taken into account.

Note that the presented 95% confidence intervals (Figs. 5.15 and 5.16) determine the ranges containing the actual average values of revenues and outputs with the probability of 95%. The much bigger 95% confidence intervals for the D<sub>3</sub> category (Figs. 5.15 and 5.16) are caused by the very small number of EGDCs (just 3) belonging to this category, which results in the large uncertainty of the average values of output and revenue.



**Figure 5.15.** Mean values of revenues for the average EGDCs from the four categories (0, 1, 2, and 3) as functions of years between 2007 and 2012. The shaded areas show the 95% confidence intervals for the calculated mean revenues.



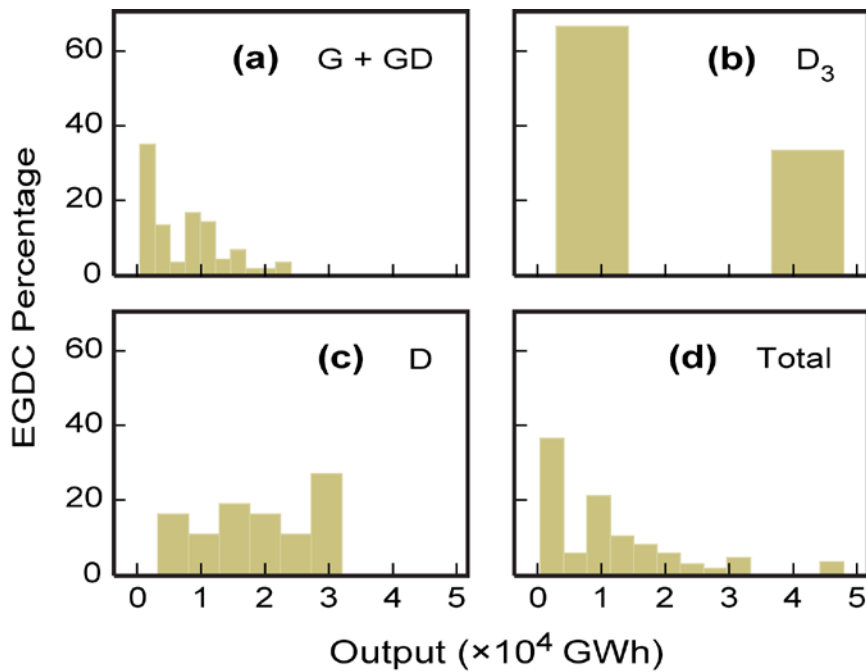
**Figure 5.16.** Mean values of the outputs for the average EGDCs from the four categories (0, 1, 2, and 3) as functions of years between 2007 and 2012. The shaded areas show the 95% confidence intervals for the calculated mean outputs.

The summary presented in Figures 5.3–5.16 illustrates that the understanding and quantitative evaluation of any trends in the existing performance data from EGDCs in Australia and, particularly, understanding and reliable evaluation of any factors causing these trends (and thus impacting on the EGDC performance) requires the detailed statistical modelling of the available data including the appropriate adjustments of the considered performance variables to each other. This is expected to identify the underlining causes for any expected (from the summary statistics) data trends, and to consider direct and indirect effects of the performance variables of other performance variables and their ratios (for more detail see Chapter 6).

# Chapter 6. EGDC Modelling

## 6.1 Introduction

As foreshadowed in the previous sections, this Chapter develops two different statistical models evaluating and analysing the available data from 30 different generating (G), generating and distributing (GD), and distribution (D) EGDCs on the Australian electricity market (Fig. 6.1).



**Figure 6.1.** Percentage distributions of EGDCs in accordance with their electricity output within the following groups: G + GD, D<sub>3</sub>, D, and over the whole data sample (Appendix 1).

Two different models will be presented in this Chapter: mixed effect model with random intercept, and generalised structural equation model (GSEM) for the identification of direct and indirect effects of different performance variables, path analysis, and identification of the major factors influencing labour and capital productivities. Practical recommendations

for optimal management/support of EGDCs and Australian electricity supply market will also be proposed and discussed.

Because 30 different EGDCs from our database (Appendix 1) will be involved in the considered statistical modelling, mixed effects must be taken into account in any of the developed models (including GSEM). Each of the 30 EGDCs was considered over six years between 2007 and 2012. It is clear that values of the performance variables for any selected EGDC over several years will be influenced by the fact that these values correspond to the same EGDC. In other words, the values of the performance variables for a given EGDC in any subsequent year are not random, but are influenced by their values in the previous year. Modelling of the data with such internal influences is conducted using mixed effects (or, equivalently, random effects) modelling (see Section 4.2.2 for further detail). Mixed effects modelling with random intercepts is used for the data where the initial data points are different for different entities contributing to the data (in our case, different EGDCs – all having different starting points corresponding to their performance in the first year of observation – 2007). Random intercepts were shown to be statistically significant and were thus used in both the models presented below in this Chapter. Consideration of statistically significant mixed effects is essential for the correct and unbiased prediction of any existing trends for separate companies, groups of companies, and valid comparisons between such companies and company groups (categories).

## **6.2 Mixed Effect Models**

One of the major performance variables for all considered EGDCs is their electricity output (Fig. 6.1) and ratios of the output to employee cost (labour productivity) and to PP&E (capital productivity). Therefore, the focus of our mixed effect modelling was on three major parameters that will be regarded as dependent (response) variables. One of the applicability

conditions for the developed mixed effect models is that the dependent variables must be normally distributed. This condition did not satisfy for the considered performance data (Appendix 1), which is why the logarithmic transformation of the data was undertaken to approximate the required normal distributions.

The outcomes of the mixed effect modelling with the indicated three dependent variables are shown in Tables 6.1–6.3. In particular, it can be seen that EGDC category, employee cost and PP&E are the only statistically significant independent variables in these models. The year variable was not statistically significant in the developed models (Tables 6.1–6.3), which is why all the presented coefficients are effectively averaged over the considered six years involved in the consideration. The coefficients in Tables 6.1–6.3 indicate the size of the impacts the respective independent (predictor) variables have on the corresponding dependent (response) variables. For example, the positive coefficient 0.73 for the D<sub>3</sub> EGDC category (category 2) shows that, for an average EGDC from the D<sub>3</sub> category, the logarithm of the output (and, in fact, the logarithms of labour and capital productivities) is larger than for an average G + GD company by 0.73. Similarly, an EGDC from the D category on average has the logarithm of the output that is larger than for an average G + GD Company by 0.85. The negative significant coefficients for the employee cost variable in Table 6.2 and for the PP&E variable in Table 6.3 are expected, as the corresponding dependent variables in these models is the output divided by employee cost and PP&E, respectively (i.e., increasing PP&E results in decreasing capital productivity – Table 6.3; similar for the labour productivity – Table 6.2). The EGDC categories G and GD were joined together in the considered mixed effect models because there was no statistically significant difference between them in these models ( $p > 0.8$ ).

<i>Variables</i>			<i>Model parameters</i>	
<b>Response</b>	<b>Predictor</b>		<b>Coefficient</b>	<b><i>p</i>-value</b>
<b>Output</b>	EGDC Category (with respect to G + GD)	D <sub>3</sub>	0.73	0.18
		D	0.84	0.037
	Employee Cost		0.22	0.004
	PP&E		0.16	0.014

**Table 6.1.** The regression coefficients and the corresponding *p*-values for the mixed effect model with electricity output as the dependent variable. Only the independent variables with  $p < 0.2$  are shown here. All the numerical variables here were transformed logarithmically to approximate normal distributions.

<i>Variables</i>			<i>Model parameters</i>	
<b>Response</b>	<b>Predictor</b>		<b>Coefficient</b>	<b><i>p</i>-value</b>
<b>Output / EC</b>	EGDC Category (with respect to G + GD)	D <sub>3</sub>	0.73	0.18
		D	0.84	0.037
	Employee Cost		− 0.78	< 0.001
	PP&E		0.16	0.014

**Table 6.2.** The regression coefficients and the corresponding *p*-values for the mixed effect model with labour productivity as the dependent variable. Only the independent variables with  $p < 0.2$  are shown here. All the numerical variables here were transformed logarithmically to approximate normal distributions.

<i>Variables</i>			<i>Model parameters</i>	
<b>Response</b>	<b>Predictor</b>		<b>Coefficient</b>	<b><i>p</i>-value</b>
<b>Output / PP&amp;E</b>	EGDC Category (with respect to G + GD)	D <sub>3</sub>	0.73	0.18
		D	0.84	0.037
	Employee Cost		0.22	0.004
	PP&E		− 0.84	< 0.001

**Table 6.3.** The regression coefficients and the corresponding *p*-values for the mixed effect model with capital productivity as the dependent variable. Only the independent variables with  $p < 0.2$  are shown here. All the numerical variables here were transformed logarithmically to approximate normal distributions.



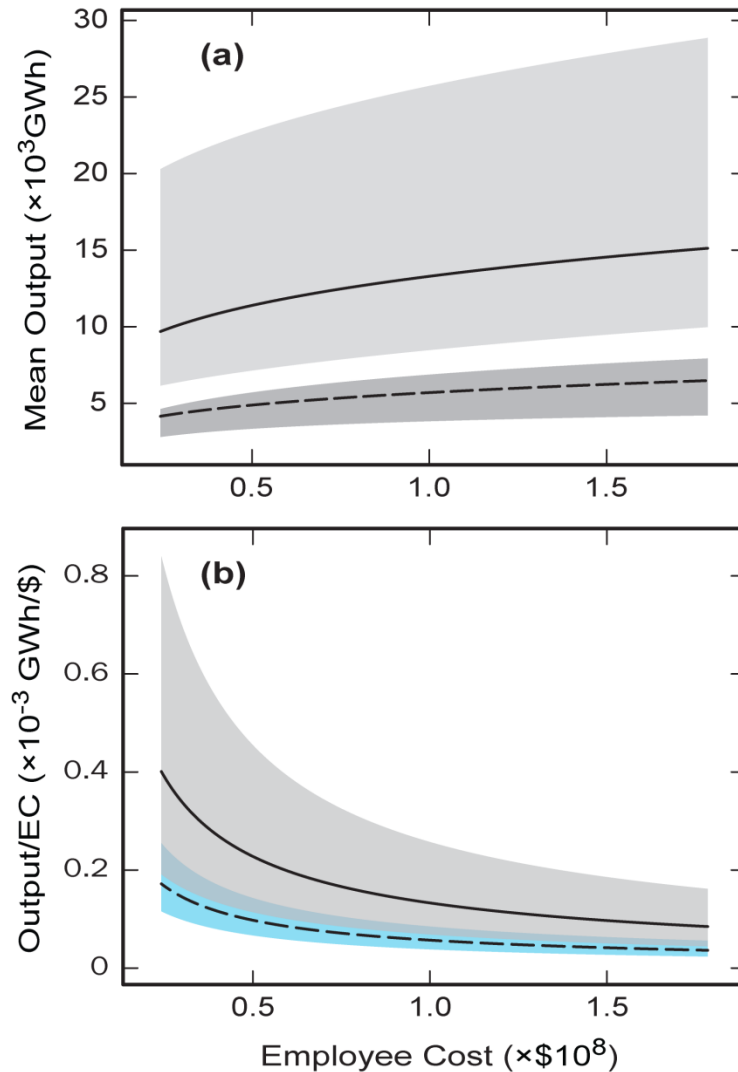
Increasing PP&R results in a significant increase of labour productivity (Table 6.2), and increasing labour productivity results in a significant increase of capital productivity (Table 6.3). This effect comes entirely from the impacts of PP&E and labour productivity on output (compare the respective coefficients in Tables 6.1, 6.2 and 6.3).

The values of the coefficients for company categories are the same for all three models (Tables 6.1, 6.2 and 6.3). This is the consequence of the logarithmic data transformation and of the fact that the categorical variables (like the four EGDC categories) cause only variations of regression intercepts and not the regression coefficients shown in the above tables. The latter statement is only correct if there are no statistically significant interactions between the categorical variable classifying the companies and the other numerical variables, and this was confirmed by the direct consideration (in the model) of any possible interactions between the independent variables and demonstration that none of them is statistically significant.

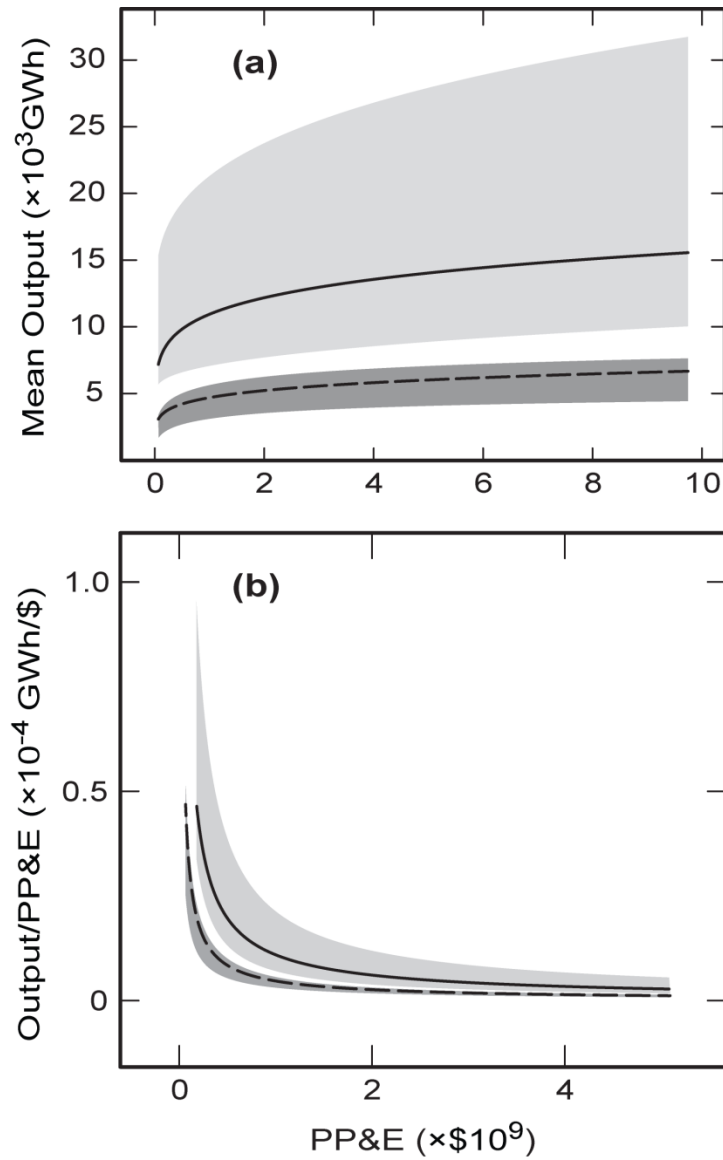
The developed models enabled us to predict the average performance of a EGDC, i.e., the dependences of the EGDC output, and/or its labour and capital productivities as functions of employee cost (Fig. 6.2), PP&E (Fig. 6.3), or any other independent (predictor) performance variable (Table 5.1). Because the year variable was not statistically significant in the developed models (Tables 6.1–6.3), the dependences presented in Figs. 6.2 and 6.3 are effectively averaged over the considered six years involved in the consideration.

It is important not to confuse the indicated 95% prediction intervals in Figs. 6.2 and 6.3 with the previously considered 95% confidence intervals (see Fig. 5.15 and 5.16). Unlike the 95% confidence intervals that are determined for the average dependences (to contain them with the 95% probability – Figs. 5.15 and 5.16), the 95% prediction intervals are those containing 95% of experimental points around the predicted curve (Figs. 6.2 and 6.3). In other words, prediction intervals determine the spread of the experimental points around the

predicted curve. Prediction intervals are typically much larger than the confidence intervals, as the latter determine the accuracy of prediction of the dependence (curve), which is typically characterised by much smaller uncertainties compared to the spread of the experimental points around it.



**Figure 6.2.** The predicted dependences: (a) mean output versus employee cost, and (b) labour productivity on employee cost for G + GD EGDCs (i.e., for category 0 + category 1: dashed curves) and D EGDCs from cluster 1 (category 3: solid curves). The shaded areas indicate the 95% prediction intervals for the curves. All four curves were determined on average for the 6 considered years between 2007 and 2012.



**Figure 6.3.** The predicted dependences: (a) mean output versus PP&E, and (b) capital productivity on PP&E for G + GD EGDCs (i.e., for category 0 + category 1: dashed curves) and D EGDCs from cluster 1 (category 3: solid curves). The shaded areas indicate the 95% prediction intervals for the predicted curves. All four curves were determined on average for the 6 considered years between 2007 and 2012.

Despite the two shaded areas (representing the 95% prediction intervals) overlap with each other in Fig. 6.2b, the two predicted curves is significantly different, as the prediction intervals do not determine the accuracy of the predicted curve (see above for the explanation of the prediction and confidence of intervals). As a result, D EGDCs are consistently

characterised by significantly larger outputs than G and GD EGDCs for all considered values of employee cost and PP&E (Figs. 6.2a and 6.3a). Similarly, D EGDCs are also characterised by significantly larger labour and capital productivities than G and GD companies for all considered values of employee cost and PP&E (Figs. 6.2b and 6.3b).

In addition, the obtained dependences of output versus employee costs (Fig. 6.2a) and versus PP&E (Fig. 6.3a) are significantly non-linear, with the slopes of the predicted curves becoming smaller at large values of employee cost and PP&E. Therefore, if we define the company size as its PP&E value or Employee Cost value (which is reflective of the amount of company assets and labour force), the growth of the output tends to slow down with increasing EGDC size (Figs. 6.2a and 6.3a). The strongest impacts of changing PP&E and employee cost occur at relatively small values of employee cost and PP&E. As a result, according to the developed models, smaller EGDCs of any type (G, GD, or D) are likely to be more efficient with regard to their labour and capital productivity, despite the reducing electricity output (Figs. 6.2b and 6.3b).

Therefore, under the developed models based on the Australian EGDCs and the existing electricity generation market, a rather unexpected conclusion is that a useful trend would be towards reasonably reduced average size of EGDCs of all types to ensure higher levels of labour and capital productivity. This is one of the significant findings of the current thesis and a practical recommendation, particularly to government regulating authorities, to stimulate and support reasonable division of particularly large EGDCs to generate a wider market of smaller more efficient and productive companies.

There is a typical critical size of EGDC below which labour and capital productivities rapidly increase (Figs. 6.2b and 6.3b). It can be seen that the critical values of PP&E and employee cost could be somewhat different for different types (categories) of EGDCs, and could be listed as follows (Figs. 6.2b and 6.3b):

$$(PP\&E)_c \approx \begin{cases} \$1 \text{ billion} & \text{for } G+GD \text{ EGDCs;} \\ \$2 \text{ billion} & \text{for } D \text{ EGDCs;} \end{cases} \quad (6.1)$$

$$(EC)_c \approx \begin{cases} \$50 \text{ Million} & \text{for } G+GD \text{ EGDCs;} \\ \$75 \text{ Million} & \text{for } D \text{ EGDCs;} \end{cases} \quad (6.2)$$

Where EC stands for ‘employee cost’. Higher productivity is typically achieved for EGDCs where both  $PP\&E < (PP\&E)_c$  and  $EC < (EC)_c$  – see Figs. 6.2b and 6.3b. It can also be seen that smaller EGDCs are also more sensitive to variations of PP&E and EC, which is illustrated by the increasing slope of the dependences in Figs. 6.2b and 6.3b at smaller values of PP&E and EC.

It can be seen from here that D EGDCs are less susceptible to increased size than G and GD EGDCs for which the critical values of PP&E and employee cost are about 1.5 – 2 times smaller than for D EGDCs – see Eqs. (6.1) and (6.2). These critical values of PP&E and employee cost largely determining the EGDC size present important evaluative and predictive performance criteria that can be used by government authorities and EGDC management in their practical and informed decision-making in relation to the company performance, productivity, and expected (predicted) growth through capital and labour investments.

### 6.3 Generalised Structural Equation Model (GSEM)

The mixed effect regression models developed in the previous section had some disadvantages and shortcomings. For example, standard mixed effect regression models may be poorly suited for the analysis of independent variables that significantly correlate with each other, in which case some of the dependent variables may show artificially low statistical significance. In addition, mixed effects models do not show mutual influences of

the independent variables on each other, which could create difficulties with the identification of paths and causes of impacts of variables and factors, and for the determination of their direct and indirect effects on each other and on the dependent variable(s).

In our case, it is quite clear that the considered independent performance variables are likely to significantly correlate with each other. For example, the employee number variable should obviously correlate with employee cost; the year variable could correlate with other variables (e.g., with employee cost, PP&E, etc.), as these variables may consistently change over the years of observation. This is likely to be at least one of the reasons for such variables as employee number and year not to appear in the developed mixed effect regression models considered above in Section 6.2. Another possible reason for these variables to be missing from the standard mixed effect models (Section 6.2) could be that employee number and year do not have direct impacts on the output dependent variable.

In the event of such difficulties and in the presence of significantly correlated independent variables, other statistical models, such as structural equation modelling (SEM), is typically used to allow the proper identification and analysis of chain-like interaction between the variables. In this model, an independent variable may have direct and indirect effects on other variables (see Section 4.2.3 for more detailed description of direct and indirect effects). For example, changing number of employees does not affect output directly, but it impacts on the employee cost variable, while the employee cost (mediating) variable impacts directly on electricity output (Fig. 6.4). Similarly, the year variable does not have a direct effect on output, but it has direct effects on PP&E and employee cost, which have direct effects on output (Fig. 6.4). In this case, we say that the year variable has indirect effects on output through the mediating variables of PP&E and employee cost. Similarly, the D<sub>3</sub> EGDC category in Fig. 6.4 has an indirect effect on output through the two mediating variables of employee number and employee cost.

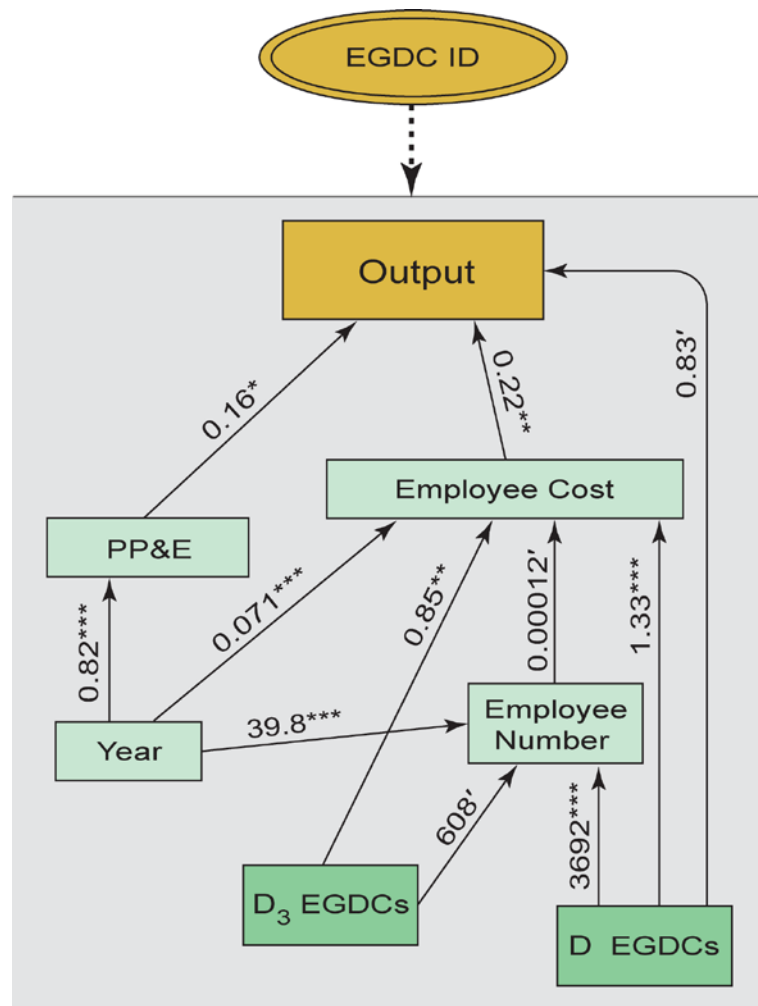
As explained in the Methodology Chapter 4 (Section 4.2.3), one of the difficulties is that the SEM analysis does not normally allow involvement of categorical variables (EGDC categories) and mixed effects. Fortunately, Stata13 software package used in this study includes the generalised SEM (GSEM) package allows the analysis of categorical variables and mixed effects.

The resultant GSEM structure for the developed model with the EGDC performance data (Appendix 1) is shown in Fig. 6.4. To obtain this model, all numerical variables (except for employee number and year) were logarithmically transformed to approximate the normal distributions. The arrows in the figure show the direct effects for all pairs of variables. Only statistically significant direct effects (with the levels of significance below 10%) are shown in Fig. 6.4. Each arrow corresponds to a regression between the considered pair of variables. The numbers shown next to the arrows are the corresponding regression coefficients. Statistical significance of these regression coefficients is shown by the asterisks: (\*\*\*)  $p < 0.001$ ; (\*\*)  $0.001 \leq p < 0.01$ ; (\*)  $0.01 \leq p < 0.05$ ; and (')  $0.05 \leq p < 0.1$ .

The ellipse on the top of Fig. 6.4 indicated as 'Company ID' indicates the considered mixed effects in the model. Because of the presence of multiple regressions between several pairs of variables (see the arrows in Fig. 6.4), mixed effects were considered and included in each of these regressions involved in the GSEM structure. All of these mixed effects were statistically significant. Covariances of the considered mixed effects were not included in the modelling due to the sample size insufficient for this purpose.

Interactions between all the variables were considered, but were not statistically significant (with  $p > 0.4$ ), except for the interaction between the D EGDCs (category 3) and employee number ( $p < 0.001$ ). However, this significant interaction was obtained when considering partial GSEM involving all the variables affecting employee cost (but with no output and PP&E – see Fig. 6.4). The confirmation of this interaction in the overall GSEM

model involving all of the considered variables (Fig. 6.4) could not be obtained due to the lack of model convergence caused by the insufficient sample size. Therefore, it was decided not to consider this interaction in the developed model (Fig. 6.4), and the question involving this interaction has been left out for future studies.



**Figure 6.4.** GSEM structure for company output as the dependent variable including all statistically significant independent and mediating variables, as well as the level of inflation over the considered years. Company ID on the top indicates mixed effects in the GSEM structure within the shaded area. Only statistically significant variables and effects are shown in this figure (with the levels of significance under 10%).

The regression coefficients shown in the GSEM model determine the effects size of the corresponding variables. For example, changing year by 1 results in variation of the



logarithm of PP&E by 0.84 and of the logarithm of employee cost by 0.073 (Fig. 6.4). Similarly, variation of the logarithm of employee cost by 1 results in the variation of the logarithm of output by 0.22. Company type (defined by the company categorisation) is the categorical variable. For categorical variables, the GSEM coefficients give the values of variable variations compared to the base category of the categorical variable. For example, for D EGDCs (category 3), the number of employees is larger than for the base G category by 3692 (Fig. 6.4). Similarly, the logarithm of employee cost for D EGDCs is larger by 1.32 than the logarithm of employee cost for G EGDCs (Fig. 6.4), etc.

Further outcomes of the conducted GSEM analysis are included in Table 6.4 including the corresponding *p*-values for the presented coefficients. In particular, it can be seen that the GD EGDCs are not statistically different from the base category with G EGDCs.

<i>Variables</i>			<i>Model parameters</i>	
<b>Response</b>	<b>Predictor</b>		<b>Coefficient</b>	<b><i>p</i>-value</b>
<b>Output</b>	EGDC Category (with respect to G)	GD	-	0.9
		D <sub>3</sub>	-	0.2
		D	0.83	0.056
	Cost of Employees		0.22	0.006
	PP&E		0.16	0.025
<b>Employee Cost</b>	EGDC Category (with respect to G)	GD	-	0.2
		D <sub>3</sub>	0.85	0.004
		D	1.33	< 0.001
	Number of Employees		0.00012	0.076
	Year		0.071	< 0.001
<b>Employee Number</b>	EGDC Category (with respect to G)	GD	-	0.97
		D <sub>3</sub>	608	0.068
		D	3692	< 0.001
	Year		39.8	< 0.001
<b>PP&amp;E</b>	Year		0.082	< 0.001

**Table 6.4.** GSEM model outcomes. The regression coefficients together with its *p*-values resulting from the GSEM analysis (Fig. 6.4). The missing data indicate lack of statistical significance under 10%. The Output, Cost of Employees, and PP&E variables were transformed logarithmically to approximate normal distributions.

The coefficients for indirect effects for the numerical variables are calculated by multiplying the corresponding coefficients for the direct effects in the chain of influences representing the indirect effect. For example, the regression coefficient for the indirect effect Year  $\rightarrow$  PP&E  $\rightarrow$  Output (Fig. 6.4) can be calculated by multiplying the respective regression coefficients from Table 6.4:  $0.082 \times 0.16 \sim 0.0131$ . The significant indirect effects of the year variable occurring in the GSEM structure shown in Fig. 6.4 can be listed as follows:

Year  $\rightarrow$  PP&E  $\rightarrow$  Output

$$(K = 0.013; p = 0.026); \quad (6.1)$$

Year  $\rightarrow$  Employee Cost  $\rightarrow$  Output

$$(K = 0.016; p = 0.007), \quad (6.2)$$

Year  $\rightarrow$  Employee Number  $\rightarrow$  Employee Cost  $\rightarrow$  Output

$$(K = 0.0011; p = 0.082). \quad (6.3)$$

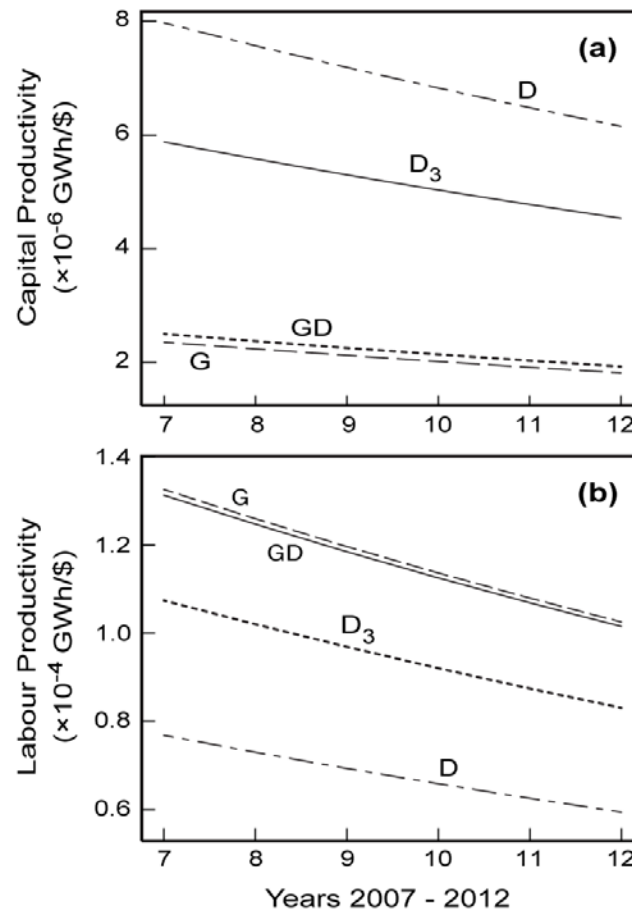
The last indirect effect is outside of the 5% significance limit, as its  $p$ -value is 0.082. This is because the mediating variable of employee number has low level of significance (Table 6.4 and Fig. 6.4), which results in even lower significance for the complete indirect effect (Eq. (6.3)). Nevertheless, the total effect of year on output, which is equal to the sum of all three indirect effects given by Eqs. (6.1) – (6.3), is significant with the regression coefficient of 0.030 and  $p = 0.007$  (which is the smallest  $p$ -value out of the three given by Eqs. (6.1) – (6.3)). This coefficient determines the overall predicted variation of output (averaged over all EGDCs and their categories) as function of year during the period of observation between 2007 and 2012.

However, significantly more interesting could be the observation that the effect of year on output goes through two distinctly different paths – through PP&E (Eq. (6.1)) and through Employee Cost (Eqs. (6.2) and (6.3)) as the mediating variables – see also Fig. 6.4. These two mediating variables are associated with capital and labour productivity, respectively. Therefore, the two distinctly different paths for the indirect effects of the year variable (through these mediating variables) also have an association with capital and labour productivity. The indirect effect of year on output through PP&E is given by Eq. (6.1) with  $K = 0.013$  and  $p = 0.026$ , whereas the total indirect effect of year on output through Employee Cost will be the sum of the two indirect effects given by Eqs. (6.2) and (6.3), with  $K = 0.017$  and  $p = 0.007$ . It can, therefore, be concluded that capital and labour productivities change similarly in time, which does not create distinct preferences for capital or labour investments on the Australian electricity generation/distribution market. This is further corroborated by the closeness of the coefficients for the direct effects of PP&E and Employee Cost on Output (Fig. 6.4 and Table 6.4).

For more detailed and consistent analysis of labour and capital productivities on the Australian electricity market, we need to derive (from the developed GSEM model) the ratios of Output/PP&E (capital productivity) and Output/EC (labour productivity), which are incorporated into the links between PP&E and Output, and between Employee Cost and Output in Fig. 6.4.

Figure 6.5 shows the dependences of capital and labour productivities predicted from the developed GSEM model as functions of years during the period of observation for the four different EGDC categories. One of the immediate and general trends that could be seen from this figure is the consistent reduction of both labour and capital productivities for all EGDC categories over the period of observations by around  $\sim 15\% - 20\%$ . This is a significant general finding illustrating the need for adequate measures on behalf of the EGDC

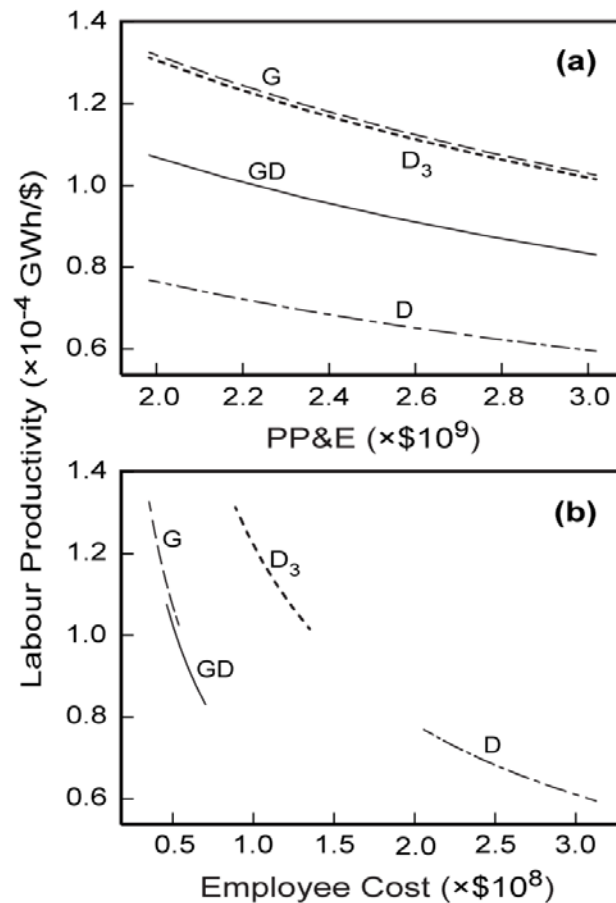
management and government to reverse this trend and ensure sustainable increase of the efficiency of the industry. Interestingly, this trend is consistent with the previous findings of early maladaptation signs of the Australia power industry (Barnett and O'Neill, 2010; Quezada, et al, 2014) and reduction of the productivity in the Australian utility industries including power supply (Eslake and Walsh, 2011).



**Figure 6.5.** Predicted capital productivities (a) and labour productivities (b) for the four indicated EGDC categories as functions of years between 2007 and 2012.

The second significant observation from Fig. 6.5 is that capital productivity is significant higher for distribution EGDCs (and, particularly, for larger D EGDCs) than for smaller generation (G) and generation & distribution (GD) EGDCs (Fig. 6.5a). This is fully consistent with the previous observation derived from the standard mixed effect regression model (Fig. 6.3b), which represents a further corroboration of the validity of this finding. At

the same time, Fig. 6.5b suggests larger labour productivity for smaller G and GD EGDCs, which is seemingly contrary to the previous findings in Fig. 6.2b. In fact, there is no any discrepancy between these outcomes. This is because, in Fig. 6.5b, the dependences of labour productivities were plotted as functions of years for EGDCs that, in fact, have significantly different typical employee costs. The dependences for G and GD EGDCs in Fig. 6.5 were plotted for significantly lower employee costs (corresponding to these EGDCs) than the dependences for D EGDCs with significantly higher employee costs (Table 5.2). This was the reason for Fig. 6.5 to show larger labour productivities for G and GD EGDCs than for D EGDCs.



**Figure 6.6.** Predicted labour productivities for the four indicated company categories as functions of: (a) PP&E, and (b) Employee Cost averaged over the years 2007 to 2012. Sub-plot (b) is plotted within the real ranges of Employee Cost for each company category.

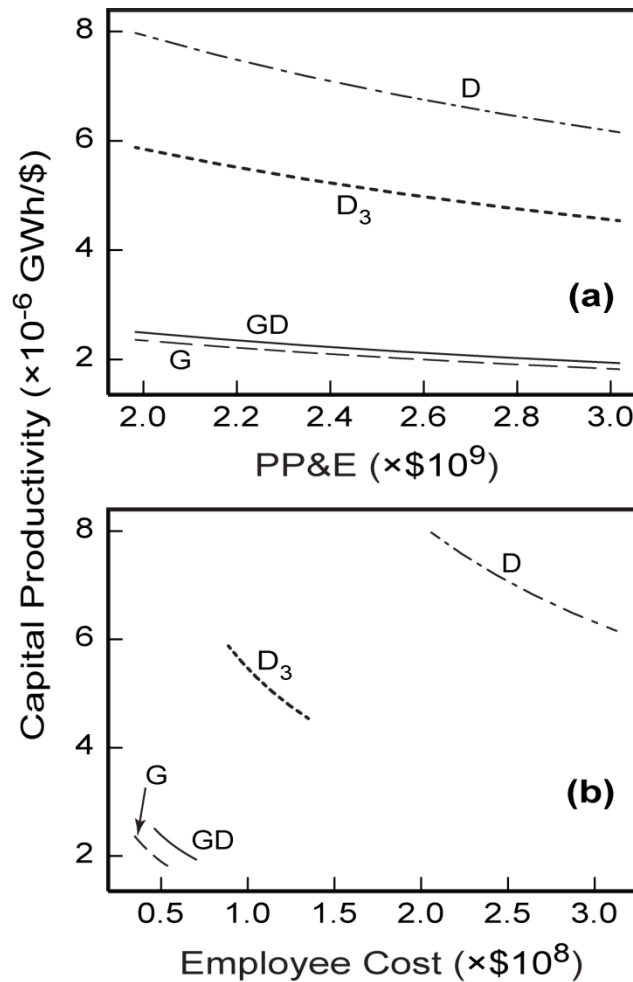
This explanation is further corroborated by Fig. 6.6b plotted for the actual ranges of employee costs within the four categories of EGDCs. It can be seen from this figure that the predicted (from the GSEM model) labour productivities are significantly higher for G EGDCs than for D EGDCs, which is consistent with Fig. 6.5b. However, this is only due to the difference in ranges of the considered values of Employee Cost (Fig. 6.6b). This is the reason for labour productivity to appear higher for G chains than for D chains (Fig. 6.5b). At the same time, it is quite clear that if the dependence for G EGDCs in Fig. 6.6b is extended further into the range of larger employee costs typical for D EGDCs, then this extended dependence will be significantly below the dependence for D EGDCs. In other words, if considered for the same values of Employee Cost, Labour Productivity for G and GD EGDCs is always lower than for D EGDCs (which is consistent with Fig. 6.2b). As a result, Fig. 6.2b and Fig. 6.5b are both correct, and there are no contradictions between them.

Unlike Figs. 6.2b and 6.5b, Figs. 6.3b and 6.5a do not display any seemingly contradictory outcomes. This is because, despite the significant differences in ranges of values of Employee Cost (company size) for different EGDC categories, G EGDCs still have lower capital productivities compared to D EGDCs (Fig. 6.7b).

Thus, Fig. 6.5 is important to demonstrate the actual performance efficiencies (reflected by the labour and capital productivities) in the electricity supply industry in Australia including the indicated important general trends (see above), irrespectively of size of EGDCs. Figures 6.6 and 6.7 significantly add to these findings by also considering the actual ranges of Employee Costs (EGDC size) for the considered 4 EGDC categories.

It is rather expected that labour productivity depends stronger on Employee Cost (Fig. 6.6b) compared to capital productivity (Fig. 6.7b), and that labour productivity depends weaker on PP&E than capital productivity (compare Figs. 6.6a and 6.7a). This is because of the definitions of the capital and labour productivities as output divided by PP&E and

Employee Cost, respectively. At the same time, it is an interesting outcome that labour productivity significantly depends on PP&E (Fig. 6.6a), whereas capital productivity significantly depends on Employee Cost (Fig. 6.7b). These dependences are related to the fact that output depends on both PP&E and Employee Cost (Figs. 6.2 and 6.3).



**Figure 6.7.** Predicted capital productivities for the four indicated EGDC categories as functions of: (a) PP&E, and (b) Employee Cost averaged over the years 2007 to 2012. Subplot (b) is plotted within the real ranges of Employee Cost for each EGDC category.

It is important to understand that the obtained dependences (Figs. 6.2–6.7) are those predicted by the developed statistical mixed effect and GSEM models. They represent the best possible (under the considered sample size) estimate of the expected performance of EGDCs within each of the categories over the considered period. These dependences are

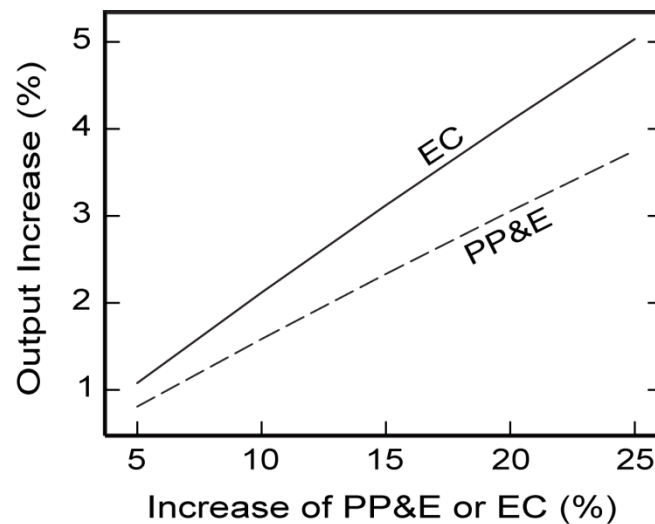
adjusted to all other variables and performance factors. Therefore, in the event of any discrepancies with the previously obtained summary outcomes (Chapter 5), strong preferences should be given to the findings presented in this Chapter 6, including the mixed effect regression model and GSEM, as well as Figs. 6.2–6.7.

Another important issue is that the trends and relationships predicted by the considered models in this Chapter are those obtained on the basis of statistical comparison between the considered EGDCs within the adopted EGDC categories from the available sample size. Therefore the predicted trends are those reflecting the distribution of the currently operating EGDCs in terms of their performance and efficiency. They may not necessarily be relevant to a particular EGDC. For example, the  $D_3$  curve in Fig. 6.7b predicts that a  $D_3$  EGDC currently operating on the market and having the employee cost of  $\sim \$10^8$  has the predicted capital productivity of around  $\sim 6 \times 10^{-6}$  GWh/\$, whereas *another*  $D_3$  EGDC having the employee cost of  $\sim \$1.5 \times 10^8$  has the capital productivity of around  $\sim 5 \times 10^{-6}$  GWh/\$. The conducted modelling does not allow to say with certainty that, if the employee cost for a selected  $D_3$  EGDC is increased from  $\sim \$10^8$  to  $\sim \$1.5 \times 10^8$ , then this will always result in a reduction of its capital productivity from  $\sim 6 \times 10^{-6}$  GWh/\$ to  $\sim 5 \times 10^{-6}$  GWh/\$. Nevertheless, because the described trends and dependences are based on the existing cohort of currently operating EGDCs, any trends for this cohort are likely to be also relevant to individual EGDCs (subject to the individual management approaches and specific operational conditions).

Therefore, the presented predicted dependences of capital and labour productivities on year (Fig. 6.5), PP&E and Employee Cost (Figs. 6.2b, 6.3b, 6.6 and 6.7) provide information that will be practically useful for EGDC management and government regulating authorities. These figures demonstrate general trends and, thus, likely impacts of capital and labour investments or restructure on the operation efficiency of EGDC, as well as of the impacts of



any variation to the EGDC profile (e.g., transformation of a D EGDC into a GD EGDC, or so). The obtained findings provide essential evidence-based indications of the performance characteristics of EGDCs, differences between them, and potential variations in performance with changing their PP&E, Employee cost, and/or type of services/product (EGDC category).



**Figure 6.8.** Percentage increments in EGDC output as functions of percentage increments of Employee Cost (solid curve) and PP&E (dashed curve).

To obtain more direct and explicit information about the predicted variations of EGDC output with relatively small variations of PP&E and/or Employee Cost (which could be typical for managerial changes), direct calculations were undertaken to quantify those as percentage variations (Fig. 6.8). On the horizontal axis in Fig. 6.8, we have either percentage increase of PP&E or Employee Cost. Solid curve should be considered where Employee Cost percentage variations are considered on the horizontal axis, whereas dashed curve should be used where PP&E percentage variations are used on the horizontal axis. For example, if PP&E of EGDC is increased by 25%, the predicted increase of the EGDC output will be about 3.8% (dashed curve in Fig. 6.8). Similarly, if Employee Cost is increased by 25%, the predicted increase of EGDC output will be about 5% (solid curve in Fig. 6.8). Therefore, Fig. 6.8 is expected to be particularly useful for decision-making by EGDC managers and

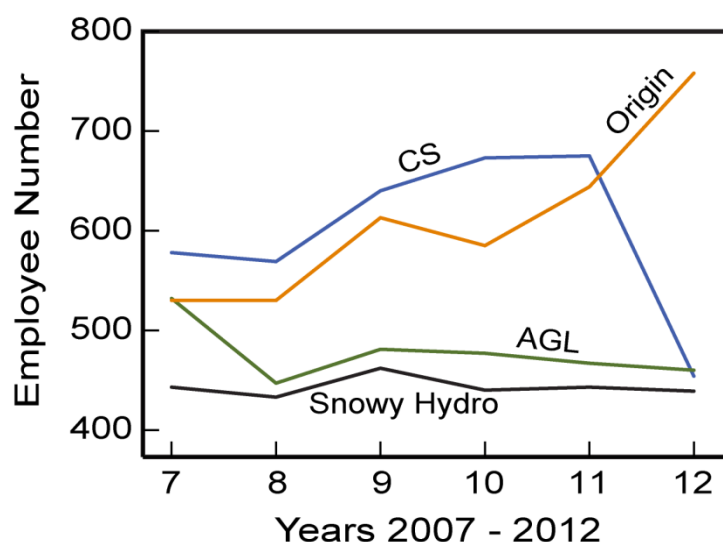
government regulating authorities to regulate and optimise the existing electricity supply market. For example, as was indicated above, smaller EGDCs systematically tend to have larger capital and labour productivities. Therefore, Fig. 6.8, in combination with the previous Figures 6.2, 6.3, and 6.5–6.7, will provide the comprehensive information about the predicted EGDC output and productivities to ensure the most informed decision-making in relation to company and market development, based in the developed predictive models.

It should be noted that, in the considered approximation of negligible interactions between the categorical variable of company type and other performance variables, Fig. 6.8 is correct for all considered EGDC categories. However, it should also be kept in mind that, as explained above, there was significant interaction between D EGDCs (category 3) and Employee Number ( $p < 0.001$ ). This interaction was, nevertheless, neglected in the developed GSEM model because of the impossibility of its inclusion in the final GSEM model due to the sample size limitations. This is one of the overall limitations of the conducted modelling, analyses, and obtained outcomes.

## **6.4 Four Case Studies**

In this section, we provide the more detailed discussion of the four rather typical examples of GD EGDCs – CS Energy, Origin Energy, Snowy Hydro, and AGL – with different sources of energy (see Chapter 3). These example EGDCs were chosen from the same category GD, but with different energy sources, to shed more light on operational and performance similarities and differences for individual companies from the same category.

It can be seen that the selected examples of the GD EGDCs are fairly similar in terms of the numbers of employees (Fig. 6.9), with Origin displaying a significant growth in staff, CS Energy a noticeable decrease, and the other two company remaining pretty much stable over the considered years.

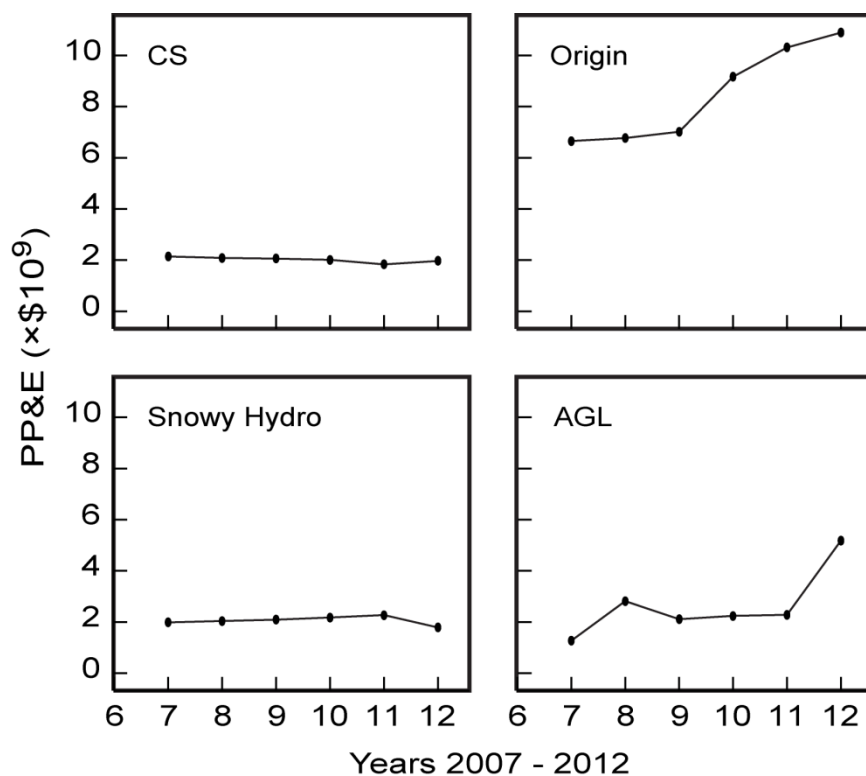


**Figure 6.9.** Dependences of employee numbers on years 2007 – 2012 for the four example GD EGDCs.

The likely reason for the significant reduction in the workforce of CS Energy is its poor financial performance in 2009–2013 with significant financial losses commencing from the 2009-2010 financial year (Section 3.3.7). This was caused by low plant reliability, coal supply and quality issues, unfavourable market conditions and reduced load output, low average pool prices and falling contract prices (CS Energy Ltd., 2015).

The significantly increased numbers of employees in Origin (Fig. 6.9) is likely to be a reflection of the aggressive expansion approach adopted by this EGDC, including active exploration of new opportunities in energy sources including gas, oil, and very significant investments in renewable power sector, making this EGDC the leading retailer of ‘green’ energy (Section 3.4). Origin adopted the business strategy to pose itself favourably within any future carbon emission restrictions and/or regulations, while such a strategy may require additional labour investments reflecting the growing employee numbers (Fig. 6.9). In addition, the apparent profitability of the Origin EGDC and good financial state during the period of time considered in this study (Section 3.4.6) was another presumed contributor to the rapidly growing employee numbers (Fig. 6.9).

The other two EGDCs – Snowy Hydro and AGL – demonstrate high levels of stability in their workforce (Fig. 6.9). One of the possible factors for such stability is the on-going solid performance of both these EGDCs (Sections 3.1.7 and 3.2.7). From 2009, the increased rainfall associated with the end of the drought period resulted in a significant water inflow into the hydro power plants of Snowy Hydro, which resulted in a significant increase of the EGDC profits (Section 3.1.7). On the other hand, additional reliance on gas-fired power stations helped moderate drought-related difficulties in the prior years, which results in financial stability and security causing stable workforce (Fig. 6.9). Similar situation was with AGL that also displayed strong financial performance with moderate increases in the net profit after tax during the period between 2008 and 2013 (Section 3.2.7).

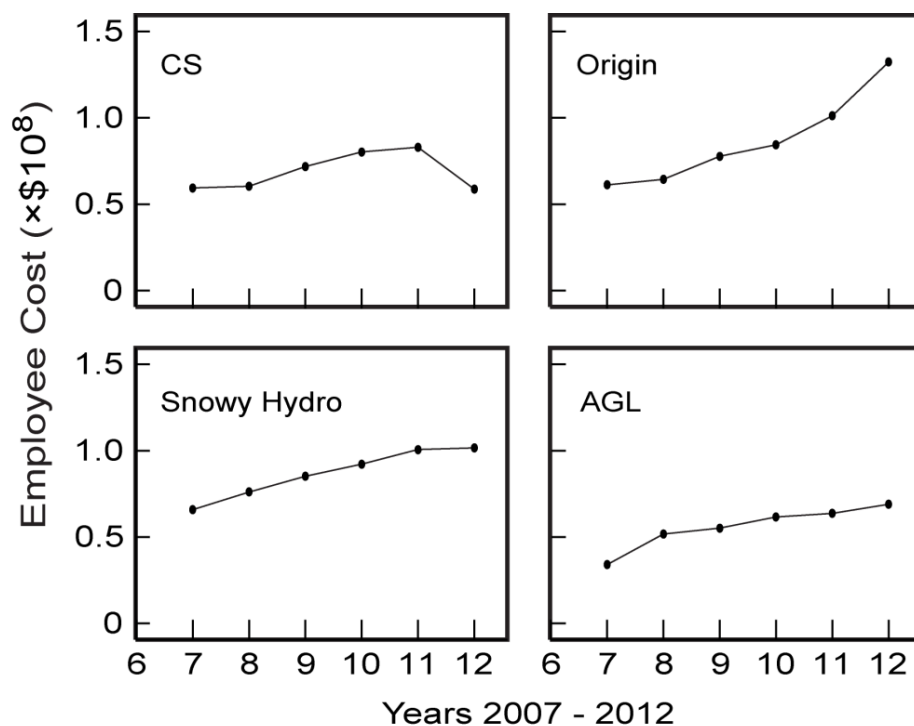


**Figure 6.10.** Dependences of PP&E on years 2007 – 2012 for the four GD EGDCs.

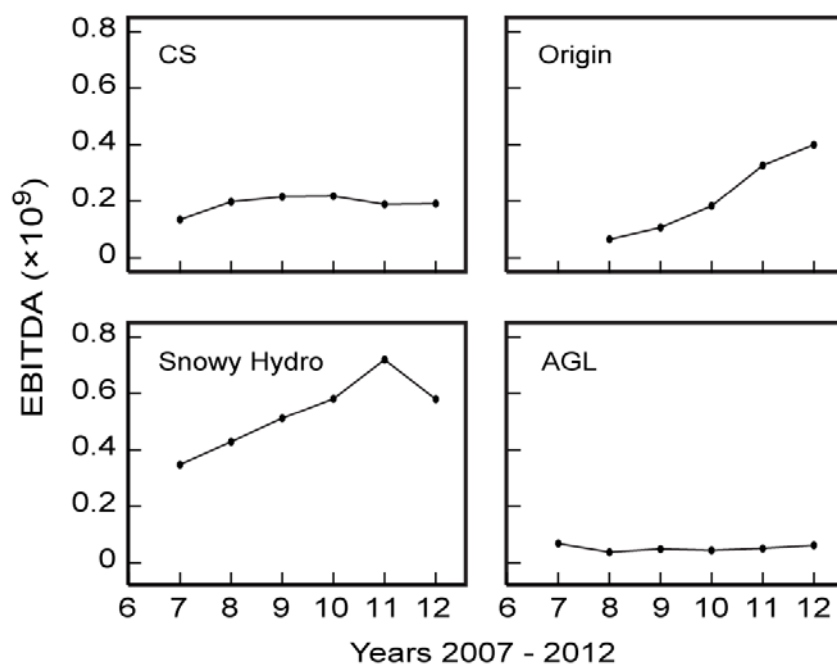
The observed PP&E trends demonstrated high level of stability for CS Energy and Snowy Hydro, and notable increases for AGL and Origin (particularly for Origin – Fig. 6.10).

This is a reflection of reliance on the existing capital resources for CS Energy and Snowy Hydro (having significant infrastructure of well-established power generating plants and facilities), and significant expansion of more dynamic and developing EGDCs exploring new opportunities, such as Origin and AGL.

Employee costs displayed general trends towards increasing for all four EGDCs (Fig. 6.11), though with some decline in the last year of observations for CS Energy, which was caused by the significantly reduced workforce for this EGDC (Fig. 6.9). The consistent increase of employee costs is also a reflection of generally growing salaries, which often tends to smooth out more significant variations (reductions) in employee numbers (compare Figs. 6.11 and 6.9).

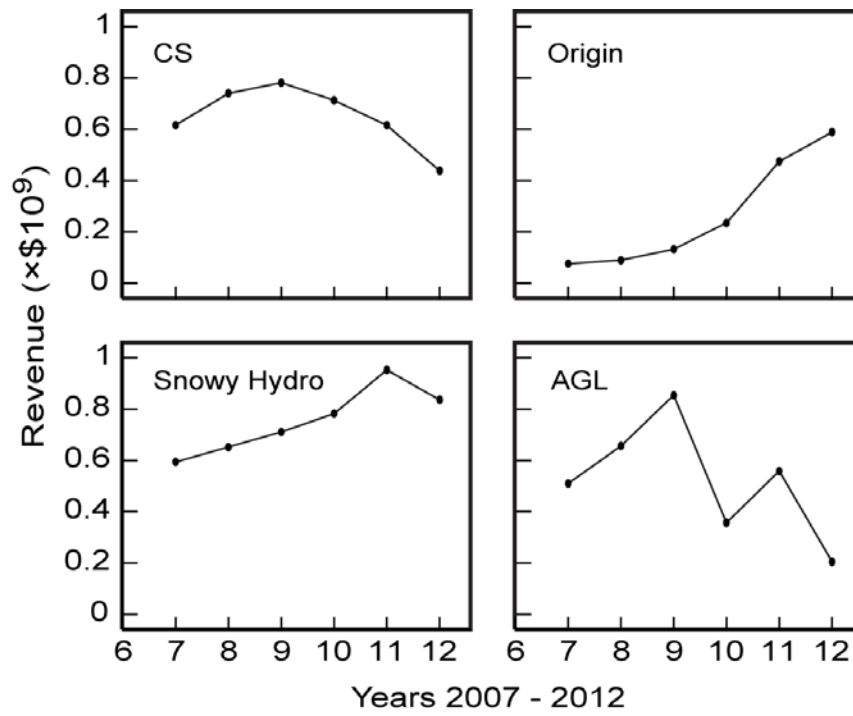


**Figure 6.11.** Dependences of employee costs on years 2007 – 2012 for the four GD EGDCs.

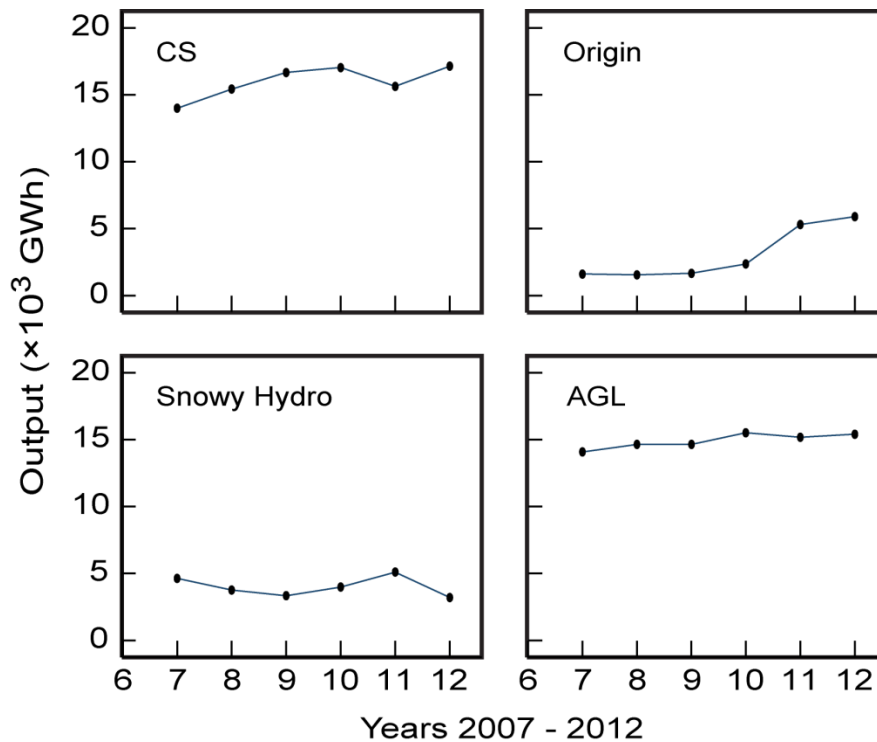


**Figure 6.12.** Dependences of EBITDA on years 2007 – 2012 for the four GD EGDCs.

The significant increases in EBITDA (Fig. 6.12) and revenue (Fig. 6.13) for Snowy Hydro were probably caused by the favourable climatic conditions associated with the transition towards the La Niña pattern characterised by increasing rainfall and water inflow into the hydroelectric power systems (Section 3.1.7). The significant increases in EBITDA (Fig. 6.12) and revenue (Fig. 6.13) for Origin were associated with the indicated aggressive strategy of this EGDC in successful exploration of new and innovative opportunities for electricity generation and distribution, which has also its reflection in notably increased output (Fig. 6.14). The other two EGDCs – CS Energy and AGL – displayed high level of stability in EBITDA (Fig. 6.12), although there was also a significant trend towards reduction of revenue over the period of observation for these two companies (Fig. 6.13), which was probably related to the softening electricity market and reduced energy demands and reduced volatility on the NEM (Sections 3.2.7 and 3.3.7).

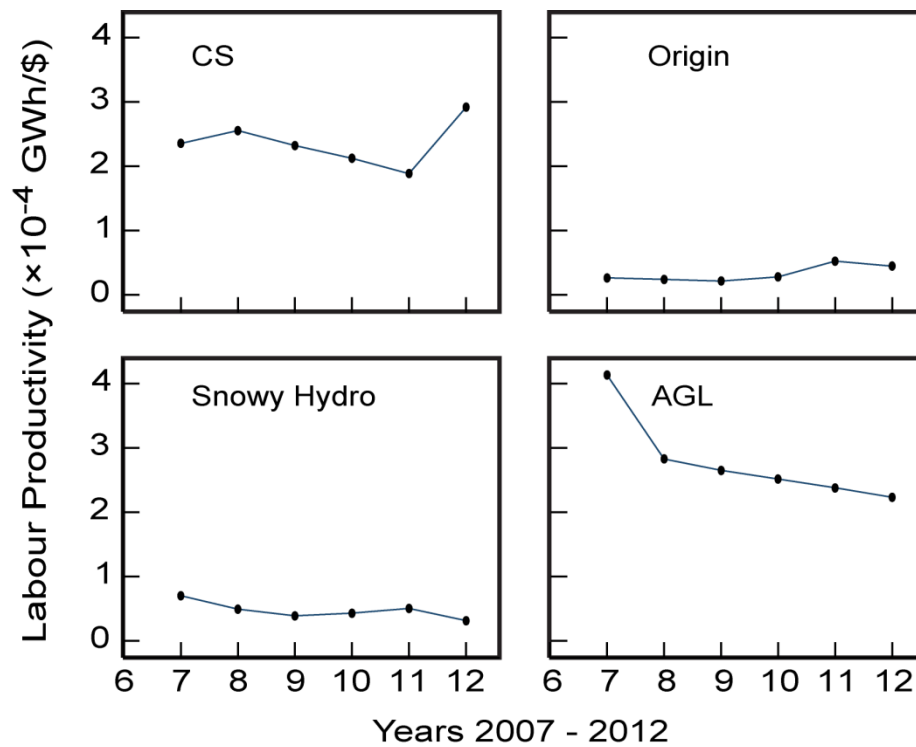


**Figure 6.13.** Dependences of Revenue on years 2007 – 2012 for the four GD EGDCs.



**Figure 6.14.** Dependences of Output on years 2007 – 2012 for the four GD EGDCs.

The generation output for all four EGDCs demonstrated high level of stability over the period of observation (apart from some increase of energy production for Origin), which is consistent with the previous findings for the four EGDC categories (Chapter 5 and the previous sections in Chapter 6).



**Figure 6.15.** Dependences of Labour Productivity on years 2007 – 2012 for the four GD EGDCs.

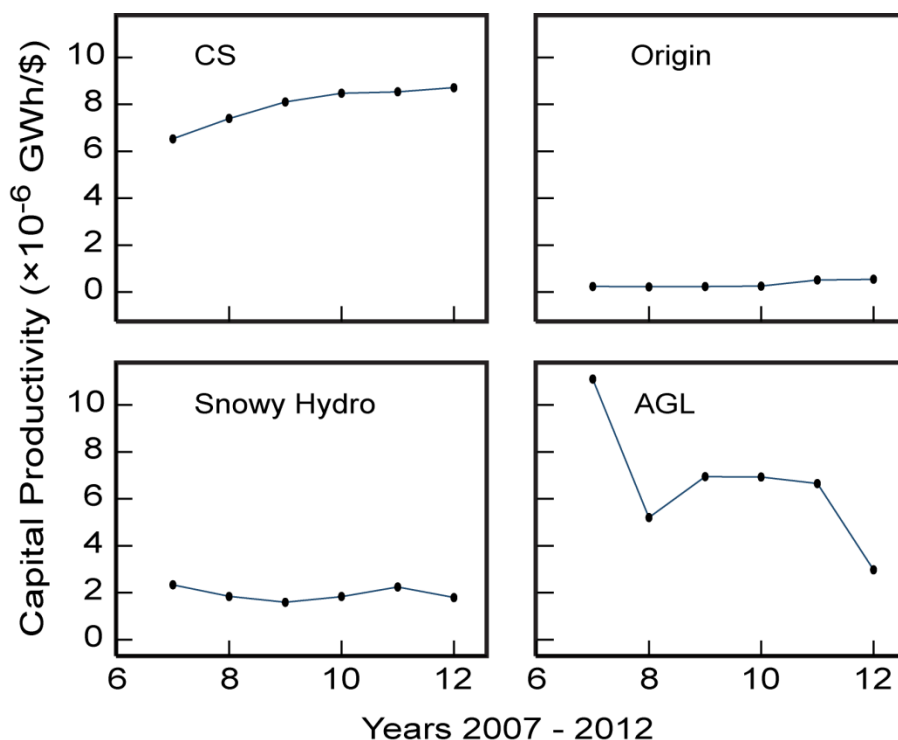
Labour productivity for all four GD EGDCs (Fig. 6.15) was either stable or reducing over the period of observation (except for CS Energy in the last year 2012, which was probably caused by the sharp reduction in employee numbers – Fig. 6.9). This is consistent with the previous findings from the mixed effect model and GSEM that labour productivity had a negative trend for all four company categories (see above). Some slight increase in labour productivity can be noticed for Origin. It is important that this positive Origin trend in labour productivity (Fig. 6.15) and stable capital productivity (Fig. 6.16) appear on the background of the simultaneous significant increases in PP&E (Fig. 6.10) and Employee Cost



(Fig. 6.11). This is in obvious contradiction with the general trends for the industry and all four categories of companies, which were the general reduction of capital and labour productivity over the period of observation and significant reduction of productivities with increasing PP&E and Employee Cost (see the above sections).

Thus, the Origin example corroborates the discussion in the paragraphs preceding Fig. 6.8 that the demonstrated industry trends should not necessarily relate to an individual EGDC. Good management and effective aggressive strategies may help defy the negative general trends in relation to labour and capital productivities, even under the condition of a significant increase in PP&E and Employee Cost. This is an important finding demonstrating that the demonstrated negative trends in the Australian electricity supply industry may be overcome through managerial approaches and government stimuli packages/interventions. Nevertheless, further research in this area is needed to further identify and confirm the major causes behind the economic and productivity success of some EGDCs. This research will have to use measurement instruments specifically evaluating impacts of a variety of economic factors and managerial decisions/approaches on improvement of capital and labour productivities, which is beyond the scope of the current study.

The observed increase of capital productivity for CS Energy (Fig. 6.16) is also an interesting observation going somewhat opposite to the indicated general trends (except for the last year of productivity increase, which could be attributed to the reduced employee cost – Fig. 6.11). Thus, CS Energy could be regarded as another example of EGDC overcoming the general trend of decreasing capital productivity with increasing employee cost. However, it is quite likely that the underlining causes for this reversed trend for capital productivity for CS Energy could be different from those for Origin Energy embracing significantly different energy production approaches and sources. The identification and explanation of these differences (if any) should be another topic for future studies.



**Figure 6.16.** Dependences of Capital Productivity on years 2007 – 2012 for the four GD companies.

Snowy Hydro further demonstrates its high stability illustrated by the nearly constant labour and capital productivities on the background of nearly constant PP&E (Fig. 6.10) and increasing employee costs (Fig. 6.11). Taking into account nearly constant employee numbers for this EGDC over the observation period (Fig. 6.9), it could be concluded that increasing employee costs (Fig. 6.11) were associated with increasing salaries and/or other staff benefits. Such an employee cost increase does not result in increasing EGDC size that was linked to reduced productivities in the developed statistical models. It is, therefore, suggested that the general negative trend of decreasing productivities with increasing EGDC size does not necessarily extend to include increasing employee costs due to increasing salaries and/or staff benefits (a company that looks after its employees may well end up with improved working efficiency duly compensating for this extra care to result in stable or even improved labour productivity).

At the same time, although the rather consistently reducing labour and capital productivities for AGL over the observation period is in the line with the discovered general trend on the Australian electricity supply market, this outcome should be considered carefully by this EGDC. The significant drop in capital productivity in 2012 could have been related to costs associated with commissioning a new plant, higher costs for maintenance of some assets, and higher depreciation and others (AGL, 2011). Although the major maintenance programs and plant enhancements conducted by AGL are expected to boost capital productivity in future, they were likely to reduce output in the short term, thus additionally contributing to the (hopefully, temporary) productivity reductions (Figs. 6.15 and 6.16).

It should also be highlighted that, irrespectively of the described trends consistent or otherwise with the general trends identified within the developed models, both labour and capital productivities for CS Energy and AGL are significantly higher over the whole period of observation than for Origin Energy and Snowy Hydro (Figs. 6.15 and 6.16). These significant differences (even within the same GD EGDC category) are probably caused by the differences in the sources of energy employed for electricity production. Cheaper coal-fired and gas-fired plants typically produce electricity under higher levels of labour and, particularly, capital productivities, whereas renewable and hydroelectric approaches may require larger levels of PP&E, thus reducing typical productivities. This is particularly relevant to Origin Energy (Fig. 6.10) that attempts significant expansion into renewable sources of electricity. This is a further illustration that, if renewable energy sources are to be effectively explored and adapted for efficient energy generation in Australia, government support and stimuluses are important to successfully and quickly overcome the productivity lag typically associated with such sources at the present time.

# Chapter 7. Conclusions

## 7.1 General Conclusions

The conducted research has made significant contributions to the fundamental and practical knowledge of the major average productivity trends and performance characteristics on the Australian power generation market. This was achieved through the development of new statistical models and effective criteria for the overall assessment of performance and productivity within distinct groups of EGDCs. The conducted classification and categorisation of EGDCs and the identified general trends will be of significant aid for decision-making and policy-making bodies and management structures within the NEM. The performance of an individual EGDC could now be compared with the average characteristics within the particular category (group) this EGDC belongs to in order to determine and better understand any deficiencies and/or advantages of the considered EGDC. This comparison can now be conducted not only on the face of some separate performance parameters, but also in a rigorous statistical way through the developed models that adjust their outcomes and predictions to all other parameters and considered variables. EGDC that performs at a level exceeding the average performance level within the respective category of EGDCs (like, for example, Origin Energy) should be regarded as a successful example on the Australian market.

In particular, the determined average productivity trends in the Australian power-generating industry have demonstrated that the previously obtained (rather limited) findings with regard to similar productivity trends and dependences, for example, on company size (Oh, 2015) are not applicable under the Australian conditions. This is because the optimal

company size determined by Oh (2015) under the Korean conditions was around 80 TWh, which is not consistent with the findings of this study. In particular, it was found that productivity significantly increases with reduction of company size below the critical size of around \$1-2 billion of PP&E assets (with the maximum PP&E being of around \$10 billion for Origin and Energex – Appendix 1), corresponding to the maximum power output of around 4.7 TWh for Powerlink and around 3 TWh for Ausgrid. This clearly demonstrates that, under the Australian power market conditions, the optimal EGDC size is significantly smaller than what was found by Oh (2015). In addition to the specificity of the Australian conditions, this significant difference could also be contributed to by the more comprehensive approach undertaken in this study, involving multiple performance variables, proper categorisation of EGDCs, and application of the comprehensive statistical models.

The conducted analysis and modelling were based on the simple definition of partial labour and capital productivities as the ratios of power output to labour cost and PP&E. This study did not involve productivity and its growth determined on the basis of the frontier analysis. This was done because we were interested in the analysis of average trends and dependences of productivity on different performance-related variables, rather in the determination of the best industry practices. However, the developed models can easily be extended/modified to involve the productivity variable calculated using different approaches including the frontier methods. This is probably one of the interesting topics for the future analysis and mathematical modelling in this area. In the meantime, the conducted study has demonstrated a significant showcase of the analytical quantitative methodology enabling the detailed and useful analysis of the average productivity trends for individual EGDCs and their reasonable groups (categories) in a strongly heterogeneous EGDC sample with rather limited size.

It was demonstrated that the current Australian electricity market is confronted by a number of challenges that require careful management to ensure that consumers continue to receive a reliable and secure supply of electricity at a competitive price (Pierce, 2012). This is the major goal and responsibility of the NEM institutions to provide such management and produce evidence-based policies stimulating and supporting the development of the electricity market and its operators. One of the important identified issues and challenges was the significant reduction by  $\sim 15\% - 20\%$  (over the observation period between 2007 and 2012) of both capital and labour productivities in the Australian electricity generation/distribution industry over all categories of EGDCs. This is consistent with the previous finding by Eslake and Walsh (2011) that the utility sector that covers the gas, electricity and water industries in Australia experienced a fall in the multi-factor productivity by  $\sim 3.7\%$  annually over the period of time between 2001 and 2010. The determined in this study reduction of the average productivity in the power supply industry in Australia is also consistent with, and could be explained (at least partially) by, the observed reduction of the electricity consumption by around 10% between 2008 and 2012 (Australian Energy Regulator, 2016), and the early signs of maladaptation of EGDCs to the new environmental and operational conditions (Barnett and O'Neill, 2010; Quezada, et al, 2014). These new conditions included, amongst other, the requirements and/or expectations of low carbon emissions and the growing contribution of the off-grid power supply systems, such as household solar power systems (Barnett and O'Neill, 2010; Quezada, et al, 2014).

The ongoing management and policy-making aimed at smooth evolution of the power generation and distribution industry in Australia require comprehensive and detailed knowledge about the state of the market, its operators, and any distinct groups of operators. The outcomes of this research provide such information and knowledge based on rigorous statistical modelling of the involved operators and identification of the major trends on the

market. As a result, the outcomes and methodologies developed in this research represent valuable tools for the NEM decision-making institutions in evaluating the electricity generation market, its operators, and undertaking informed management decisions and policies ensuring rapid development of the electricity generation industry in Australia for the benefit of the consumers and electricity producers/distributors. This aspect is particularly important, as the current electricity market in Australia involve a broad variety of strongly heterogeneous operators with a range of performance and operational characteristics that are difficult to analyse without comprehensive quantitative statistical methodologies and approaches developed in the process and as a result of this research.

*“Policy makers and market designers must comprehend the principle of cause and effect in policy design; this requires an understanding of the various interactions of policies and an appreciation of their long term effects.” (Pierce, 2012)*

The **major limitations of the conducted study** included the following:

1. This study was conducted on the basis of only Australian data on EGDCs, which means that the obtained outcomes are likely to be limited to the Australian conditions. This is further confirmed by the significantly different outcomes with regard to optimum company size obtained for the Korean conditions (Oh, 2015), although it is not entirely clear whether that difference was caused by the difference in the market conditions or by the differences in the adopted statistical methodology and/or nature of the data.
2. The conducted study was limited to only 6 years of observations between 2007 and 2012. Although the good reasons for this timeframe selection were presented and explained in Section 4.1 of the Methodology and Data Chapter, this still constitutes a

limitation for the conducted study and applicability of its outcomes under different conditions – outside of the considered timeframe.

3. The available EGDC sample size was significantly limited by the size and the existing fragmentation of the Australian power market. Despite this limitation, Chapter 6 presented statistically significant direct and indirect effects of the variables on each other, as well as the significant productivity trends (Figs. 6.2 – 6.8). At the same time, there could be other possible direct and indirect effects or trends or other outcomes (e.g., other EGDC categories) that could not be identified in this study because of the limited sample size. In addition, the small sample size did not allow inclusion of variable interactions into the GSEM model, which was a limitation (though not very significant) of that model.
4. Although the identified trends towards larger productivity across all categories with decreasing company size were statistically significant, it was not possible to determine an optimum company size for any of the EGDC categories. This is again likely to be a result of the limited sample size and, particularly, limited number of smaller EGDCs on the Australian market.
5. Another possible limitation of the study was related to the accuracy of the data collection largely relying on the data provided by the companies in their annual reports. This data could potentially lack accuracy (which was often beyond our control) and inconsistency of reporting standards. This limitation could be particularly significant outside of the selected data collection timeframe where the reporting standards were noticed to have changed. In addition, not all companies provide the information about the same variables characterising their financial, capital and labour force characteristics, which should be carefully taken into account when conducting



any comparisons or when including a particular company into an EGDC sample for statistical modelling.

6. The conducted study was limited to the described partial capital and labour productivities. Consideration of other types of productivity could potentially yield somewhat different outcomes or different trends. Therefore, care should be taken when extending the findings of this study to other types of productivity.
7. The obtained outcomes are also limited to the power generation industry.

Nonetheless, it is important to emphasise that, despite these limitations of the current study, the obtained outcomes present a significant value for the power generation industry in Australia, while further research is needed to confirm or otherwise their validity for other countries and international power markets. This study has extended (along with only few other existing but limited attempts in the literature, such as by Oh (2015)) the productivity analysis to obtain average statistical productivity trend as a function of numerous independent variables and factors, with the goal of identifying optimum company characteristics or structure. Such analysis will be particularly useful for the optimisation of policy making and development of effective regulatory framework in the power industries. Further, the developed methodology and methodological principles should be applicable to any power market of country. From this point of view, the current study has a significant international impact and benefit, and constitutes a significant contribution to knowledge in the area of productivity in power generation/distribution industries.

The obtained results and particularly the developed methodologies could also be of significant benefit and importance for industries other than power industries. Although the direct applicability of the outcomes obtained in this study is questionable when it comes to other industries, the developed statistical methods for the classification of heterogeneous

company samples and determination of networks of direct and indirect effects between productivity-related variables and factors will certainly be important and useful.

## **7.2 List of Major Achievements and Findings**

1. The development, justification and application of the cluster analysis approaches for the categorisation and classification of the Australian EGDCs in accordance with their performance parameters.
2. Identification of the 2 major clusters of EGDCs on the Australian electricity market:
  - Cluster 1: larger distribution EGDCs; and
  - Cluster 2: three groups including generation companies, generation & distribution, and smaller distribution EGDCs.
3. This study represents the first attempt of the comprehensive statistical modelling (using the two different approaches – mixed effect regression model and generalised structural equation model (GSEM)) of EGDC performance and any existing trends on the Australian electricity supply market.
4. Identification and quantification of significant direct and indirect effects of performance variables and factors on EGDC output and capital and labour productivities, including the causality chains of influence (paths) of the performance variables, company categories, and time variable on each other and company output.
5. Distribution EGDCs were shown to be characterised by significantly larger outputs and labour/capital productivities than generation and generation & distribution EGDCs with the same levels of Employee Cost and PP&E.
6. For the same company size (reflected by the PP&E and Employee Cost variables), distribution EGDCs are also characterised by significantly larger labour and capital

productivities than generation and generation & distribution EGDCs for all considered values of Employee Cost and PP&E.

(However, the larger productivity and power output for the distribution EGDCs could be an artefact related to the different nature of the generation and distribution production processes in terms of differences with handling the electric power).

7. Smaller EGDCs and companies of any type are predicted to be more efficient in terms of their labour and capital productivity. The growth of the output with increasing size of EGDC is non-linear and tends to slow down at large values of Employee Cost and PP&E, resulting in lower productivities. This general trend was obtained from both mixed effect model and GSEM.
8. Thus, a conclusion was made that EGDC size should be reasonably reduced for all types of EGDCs to ensure higher levels of labour and capital productivity. This could be regarded as one of the practical recommendations, particularly to government regulating authorities, to stimulate and support reasonable sub-division of particularly large EGDCs to generate a wider market of smaller more efficient and productive companies.
9. Development of simple criteria based on critical values of PP&E and employee cost (EC) for the approximate determination of EGDCs with higher and lower capital and labour productivities and their sensitivity to capital and labour investments:

$$\begin{aligned}
 (PP\&E)_c &\sim \begin{cases} \$1 \text{ billion} & \text{for G+GD supply chains;} \\ \$2 \text{ billion} & \text{for D supply chains;} \end{cases} \\
 (EC)_c &\sim \begin{cases} \$50 \text{ Million} & \text{for G+GD supply chains;} \\ \$75 \text{ Million} & \text{for D supply chains.} \end{cases}
 \end{aligned}$$

Higher productivity occurs where  $PP\&E < (PP\&E)_c$  and  $EC < (EC)_c$ . However, the available data did not allow the determination of an optimum size of EGDC as defined by the values of Employee Cost and PP&E.

10. Demonstration of the general negative evolutionary trend (of around  $\sim 15\% - 20\%$  reduction) over the period of observation between 2007 and 2012 for both capital and labour productivities in the Australian power industry over all categories of EGDCs.
11. Demonstration that the discovered general negative trends for the electricity supply industry in Australia can be overcome, which is demonstrated by the examples of individual companies (e.g., Oregon Energy), through appropriate and aggressive managerial decisions and approaches illustrating realistic opportunities for the successful and sustainable industry development.
12. A further demonstration that, if renewable energy sources are to be effectively explored and adapted for efficient energy generation in Australia, government support and stimulus are important to successfully and quickly overcome the productivity lag typically associated with such sources at the present time.

### **7.3 Recommendations**

The proposed recommendations to the government and EGDC management institutions/bodies are based on the above-listed major findings and achievements:

- It is recommended that the four identified different categories of EGDCs on the market be considered separately in any policy or management decision. This is because of their significantly different characteristics associated with the described clustering of the EGDC performance data.
- It is recommended to consider stimulus for further reasonable sub-division of particularly large EGDCs that are underperforming compared to the average

category level. This is because of the general trend (at least within the considered range of EGDC sizes) that decreasing company PP&E and employee costs tends to result in increased productivities.

- The recommended EGDC size depends upon the nature of its commercial activities and is indicated by the criteria at point 9 in the List of Major Achievements and Findings.
- It is also recommended to identify and analyse the underlining causes for the discovered general negative trend with decreasing both labour and capital productivities on the Australian electricity supply market.
- It is also recommended to exercise caution and take into account the predicted negative productivity trends with increasing PP&E and employee costs, when making decisions as to capital and labour investments. This should not be regarded as a warning against such investments, but rather that the investments should be considered as a significant factor that has to be taken into account and appropriately managed. The feasibility of successful company management overcoming the general trend of reduced productivities with increasing PP&E and employee costs has been demonstrated on the examples of particularly successful EGDCs (e.g., Origin Energy).
- Finally, government support and stimuluses are important and recommended to ensure successful transition to renewable energy sources, and to reduce the impact of the existing productivity lag and maladaptation associated with such a transition at the present time.

It is proposed that one of the major future research directions (that are beyond the scope of this study) should particularly focus on the identification and detailed understanding of the factors and variables (including the respective managerial decisions and approaches)

that allowed successful EGDCs, like Origin Energy, to overcome the existing consistent general trends towards decreasing productivities.

The other issue that might need further consideration and investigation is the general trend towards reducing productivities in the electricity supply industry in Australia over the observation period between 2007 and 2012. It is important to identify specific causes for these productivity decline across all of the considered EGDC categories and undertake the required measures and/or policy modifications to reverse this undesirable trend.

Further research will also be needed to extend the developed statistical models and approaches to involve the frontier models for productivity determination, including the best industry practices. It would be particularly interesting to investigate how such best industry practices evolve and change under the significantly heterogeneous nature of EGDCs in Australia, including any dependences of the best industry/group practices on various performance parameters characterising different EGDC categories determined in this study.

## References

Aberson, C. L. (2010). *Applied Power Analysis for the Behavioral Science*. Routledge, Taylor and Francis Group, NY, USA.

AGL. (2009). *Annual Report*. AGL Company Website. Retrieved from:

[http://www.agl.com.au/Downloads/2009\\_ASX\\_Annual-Report.pdf](http://www.agl.com.au/Downloads/2009_ASX_Annual-Report.pdf)

AGL. (2010a). *The Responsible Business Experts*. Energy in Action, Article 13. Retrieved from:

[http://www.article13.com/CBI/CSR\\_case\\_study\\_AGL\\_April%202010.pdf](http://www.article13.com/CBI/CSR_case_study_AGL_April%202010.pdf)

AGL. (2010b). *Annual Report*. Retrieved from:

[http://2010annualreport.agk.com.au/major\\_power\\_generation\\_and\\_upstream\\_gas\\_assets.html/](http://2010annualreport.agk.com.au/major_power_generation_and_upstream_gas_assets.html/)

AGL. (2011). *Annual Report*. AGL Company Website. Retrieved from:

<http://www.agl.com.au/Downloads/2011%20Annual%20Report%20and%20ASX%20release.pdf> .

AGL. (2012). *AGL Company Website*. Retrieved from: <http://agl.com.au/>

AGL Energy Limited. (2012). *AGL Strategy and SWOT report*. Retrieved from: <http://www.scribd.com/doc/86737960/AGL-Energy-Limited-Strategy-and-SWOT-Report/>

AGL Energy Limited. (2013). *ASX Release*. Retrieved from:

<http://www.agl.com.au/~media/AGL/About%20AGL/Documents/Media%20Center/ASX%20and%20Media%20Releases/2013/May/Merchant%20Energy%20Presentation%2020130531.pdf>

AGL Energy Limited. (2013b). *2013 Sustainability Performance Report*. Retrieved from:

[http://www.agl.com.au/~media/agl/about%20agl/documents/media%20center/what%20we%20stand%20for/2013/agl051\\_sustainability%20report\\_2013\\_hr.pdf](http://www.agl.com.au/~media/agl/about%20agl/documents/media%20center/what%20we%20stand%20for/2013/agl051_sustainability%20report_2013_hr.pdf)

AGL Energy Limited. (2014). *Proposed Acquisition of Macquarie Generation*. Retrieved from:

[http://www.competitiontribunal.gov.au/\\_data/assets/pdf\\_file/0004/24628/form-s.pdf](http://www.competitiontribunal.gov.au/_data/assets/pdf_file/0004/24628/form-s.pdf)

AGL Energy Limited. (2014b). *NSW faces gas supply shortages from winter 2016, economic paper confirms (Newcastle)*. Retrieved from:

<http://www.agl.com.au/about-agl/media-centre/article-list/2014/march/nsw-faces-gas-supply-shortages-from-winter-2016-economic-paper-confirms-newcastle/>

AGL Energy Limited. (2014c). *Sustainability Performance - Economic Performance*. Retrieved from: <http://agl2014.sustainability-report.com.au/economic-performance/>

AGL. (2015). *Annual reports*. Retrieved from:

<http://www.agl.com.au/about-agl/investor-centre/reports-and-presentations/annual-reports/>

AGL. (2015b). *AGL Loy Yang*. Retrieved from:

<http://www.agl.com.au/about-agl/how-we-source-energy/thermal-energy/agl-loy-yang/>

AGL. (2015c). *AGL secures gas supply until 2020 with Bass Strait agreement*. Retrieved from:

<https://www.agl.com.au/about-agl/media-centre/article-list/2015/april/agl-secures-gas-supply-until-2020-with-bass-strait-agreement>

AGL. (2016a). *Silver Springs gas storage*. Retrieved from:

<https://www.agl.com.au/about-agl/how-we-source-energy/gas-storage/silver-springs-gas-storage>

AGL. (2016b). *Newcastle Gas Storage Facility*. Retrieved from:

<https://www.agl.com.au/about-agl/how-we-source-energy/gas-storage/newcastle-gas-storage-facility-project>

Aigner, D.J., Lovell, C.A.K., Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *J. Econ.* 6 (1), 21–37.

Ahire, S.L., Golhar, D.Y., Waller, M.A. (1996). Development and validation of TQM implementation constructs. *Decision Sciences*, 27(1), 25–56.

Alter, C., Hage, J. (1993). *Organisations Working Together*. Beverly Hills, CA: Sage.

Anderson, E., Hu, X., Winchester, D. (2007). Forward contracts in electricity markets: the Australian experience. *Energy Policy*, 35, 3089–3103.

Arent, D., Pless, J., Mai, T., Wiser, R., Hand, M., Baldwin, S. (2014). Implications of high renewable electricity penetration in the U.S. for water use, greenhouse gas emissions, land-use, and materials supply. *Applied Energy*, 123, 368–77.

Arocena, P. (2008). Cost and quality gains from diversification and vertical integration in the electricity industry: a DEA approach. *Energy Econ.* 30 (1), 39–58.

Australian Bureau of Statistics. (2012). *The Snowy Mountains Hydro-electric Scheme*. Retrieved from:

<http://www.abs.gov.au/ausstats/ABS@.nsf/94713ad445ff1425ca25682000192af2/fde81ae268c76207ca2569de00274c14!OpenDocument/>



Australian Energy Market Operator (AEMO). (2012). *An Introduction to Australia's Energy Market*. Retrieved from: <http://www.aemo.com.au/>

Australian Energy Regulator (AER). (2010). *State of the Energy Market*. Commonwealth of Australia.

Australian Energy Regulator (AER). (2011). *State of the Energy Market*. Commonwealth of Australia.

Australian Energy Regulator (AER). (2014) *Electricity distribution network service providers. Annual benchmarking report*.

Australian Energy Regulator (AER). (2016) *National Electricity Market electricity consumption*. Retrieved from:

<https://www.aer.gov.au/wholesale-markets/wholesale-statistics/national-electricity-market-electricity-consumption>

Australian Government. (2011). *Clean Energy Bill 2011*. Federal Register of Legislation. Commonwealth of Australia. Retrieved from:

<https://www.legislation.gov.au/Details/C2011B00166>

Australian Government Productivity Commission. (2012, February). *Electricity Network Regulation Electricity. Issues Paper*.

Australian Government. (2014). *RET Review report*. Retrieved from:

<https://retreview.dpmc.gov.au/311-trends-electricity-demand/>

Australian Government: The Treasury. (2014). *Price regulations of utilities*. Retrieved from: <http://archive.treasury.gov.au/documents/194/PDF/round5.pdf>

Baker, G. (2013). *Eastern Australia Gas reserves and resources at 31 December 2012*, RLMS.

Barnett, J., O'Neill, S. (2010). Maladaptation. *Global Environ Change*, **20**(2), 211–213.

Barros, C.P. (2008). Efficiency analysis of hydroelectric generating plants: A case study for Portugal. *Energy Economics*, **30**, 59-75.

Barros, C.P., Briec, W., Peypoch, N. (2008a). Productivity growth and biased technological change in hydroelectric generating dams. *School of Economics and Management, Technical University of Lisbon*. ISSN: 0874-4548.

Barros, C.P., de Menezes, A.G., Peypoch, N., Solonandrasana, B., Vieira, J. C. (2008b). An analysis of hospital efficiency and productivity growth using the Luenberger indicator. *Health Care Manage Sci*, **11**, 373.

Battese, G. E. (1991). Frontier production functions and technical efficiency: A survey of empirical applications in agricultural economics. *35th Annual Conference of the Australian Agricultural Economics Society*, University of New England, Armidale, Australia, 11-14 February 1991.

Battese, G. E., Rao, D. S. P. (2002). Technology gap, efficiency and a stochastic metafrontier function. *International Journal of Business and Economics*, *1*(2), 87-93.

Battese, G. E., Rao, D. S. P., O'Donnell, C. J. (2004). A metafrontier production function for estimation of technical efficiencies and technology potentials for firms operating under different technologies. *Journal of Productivity Analysis*, *21*, 91-103.

Baumol, W. J. (1977). On the proper cost tests for natural monopoly in a multiproduct industry. *American Economic Review*, *67*, 809–822.

Beamon, B. (1999). Measuring supply chain performance. *International Journal of Operations and Production Management*, *19* (3), 275–292.

Beder, S. (2013, Autumn). The Real Cause of Electricity Price Rises. *Australian Options*, pp.14-16.

Briec, W., Peypoch, N., Ratsimbanierana, H. (2011). Productivity growth and biased technological change in hydroelectric dams. *Energy Econ.* *33* (5), 853–858.

Boskin, M. J. (2008). Consumer Price Indexes. In D. R. Henderson (ed.). *Concise Encyclopedia of Economics* (2nd ed.). Indianapolis, USA.

Boussemart, J.P., Briec, W., Kerstens, K., Poutineau, J.C. (2003). Luenberger and Malmquist productivity indices: theoretical comparisons and empirical illustrations. *Bull Econ Res*, **55**, 391–405.

Bozarth, C., Handfield, R., Das, A. (1998). Stages of global sourcing strategy evolution: an exploratory study. *Journal of Operations Management*, *16* (2/3), 241–255.

Brinsmead, T. S., Hayward, J., Graham, P. (2014). *Australian electricity market analysis report to 2020 and 2030 (Final Draft)*. CSIRO Report, No: EP141067.

Burton, T.T. (1988). JIT/repetitive sourcing strategies: trying the knot with your suppliers. *Production and Inventory Management Journal*, 29 (4), 38–41.

Busby, R. L. (2012). *Wind power: The industry grows up*. Tulsa: Pennwell Books.

BusinessDictionary. (2016) *Supply Chain*. Retrieved from: <http://www.businessdictionary.com/definition/supply-chain.html>

Business Monitor. (2014) *Australia Power Report 2014*, Business Monitor International, London, UK, ISSN 2041-5664.

Bustamante, M., Gaustad, G. (2014). Challenges in assessment of clean energy supply chains based on byproduct minerals: a case study of tellurium use in thin film photovoltaics. *Applied Energy*, 123, pp. 397–414.

Canadian Supply Chain Sector Council. (2016). *Supply Chain Definitions*. Retrieved from: <http://www.supplychaincanada.org/en/supply-chain>

Calinski, T., Harabasz, J. (1974). A dendrite method for cluster analysis. *Communications in Statistics – Theory and Methods A*, 3, 1–27.

Cambra-Fierro, J. J., Polo-Redondo, Y. (2008). Creating satisfaction in the demand-supply chain: the buyers' perspective. *Supply Chain Management: An International Journal*, 13(3), 211-224.

Carbon Tax. (2012). *Is Australia Ahead of Others?* Retrieved from <http://www.carbontax.net.au/australia-acting-countries>.

Carr, A.S., Pearson, J.N. (1999). Strategically managed buyer-seller relationships and performance outcomes. *Journal of Operations Management*, 17 (5), 497–519.

Carr, A.S., Smeltzer, L.R. (1997). An empirically based operational definition of strategic purchasing. *European Journal of Purchasing and Supply Management*, 3 (4), 199–207.

Carr, A.S., Smeltzer, L.R. (1999). The relationship of strategic purchasing to supply chain management. *European Journal of Purchasing and Supply Management*, 5, 43–51.

Carr, L.P., Ittner, C.D. (1992). Measuring the cost of ownership. *Journal of Cost Management*, 6 (3): 42-51.

Carson, D., Gilmore, A., Maclaran, P. (1998). Customer or profit focus: an alternative perspective. *Journal of Marketing Practice: Applied Marketing Science*, 4 (1), 26–39.

Carter, J.R., Narasimhan, R. (1993). *Purchasing and Materials Management's Role in Total Quality Management and Customer Satisfaction*. Center of Advanced Purchasing Studies/NAPM, Tempe, AZ.

CCC. (2008). *Building a low-carbon economy – the UK's contribution to tackling climate change*. Retrieved from <http://archive.theccc.org.uk/aws3/TSO-ClimateChange.pdf>

CCC. (2011). *The renewable energy review. Committee on Climate Change*. Retrieved from:

[http://www.archive.theccc.org.uk/aws/Renewables%20Review/The%20renewable%20energy%20review\\_Printout.pdf](http://www.archive.theccc.org.uk/aws/Renewables%20Review/The%20renewable%20energy%20review_Printout.pdf)

Cecere, L. M. (2014). *Supply Chain Metrics that Matter*. John Wiley & Sons.

Çelen, A. (2013). Efficiency and productivity (TFP) of the Turkish electricity distribution companies: An application of two-stage (DEA&Tobit) analysis. *Energy Policy*, 63, 300-310.

Chang, D. S., Chen, Y. T. Chen, W.-D. (2009). The exogenous factors affecting the cost efficiency of power generation. *Energy Policy*, 37, 5540-5545.

Chaudry M., Ekins P., Ramachandran K., Shakoar A., Skea J., Strbac G. (2009). Supply chain management: a perspective on partnerships. *Supply Chain Management: International Journal*, 3, 53–67.

Chen, Z., Barros, C.P., Borges, M.R. (2015). A Bayesian stochastic frontier analysis of Chinese fossil-fuel electricity generation companies. *Energy Economics*, 48, 136-144.

Chen, I. J., Paulraj, A. (2004a). Towards a theory of supply chain management: the constructs and measurements. *Journal of Operations Management*, 22, 119-150.

Chen, I.J., Paulraj, A. (2004b). Understanding supply chain management: critical research and a theoretical framework. *International Journal of Production Research*, 42 (1), 131–163.

Cherp, A., A. Adenikinju, A. Goldthau, F. Hernandez, L. Hughes, J. Jansen, J. Jewell, M. Olshanskaya, R. Soares de Oliveira, B. Sovacool and S. Vakulenko. (2012). Chapter 5 - Energy and Security. In *Global Energy Assessment - Toward a Sustainable Future* (pp. 325-

384). Cambridge, UK and New York, NY, USA: Cambridge University Press, and, Laxenburg, Austria: The International Institute for Applied Systems Analysis.

Choi, T.Y., Hartley, J.L. (1996). An exploration of supplier selection practices across the supply chain. *Journal of Operations Management* 14 (4), 333–343.

Thompson, J.D., 1967. *Organisations in Action*. McGraw-Hill, New York.

Christopher, M. G. (1998). Relationships and Alliances: Embracing the era of network competition. In J. Gattorna (Ed.), *Strategic Supply Chain Management* (pp. 272–284). Hampshire, England: Gower Press.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.), Lawrence Erlbaum Associates, USA.

Cohen, S. and Rousell, J (2004). *Strategic supply chain management: the five disciplines for top performance*. New York: McGraw Hill.

Collin, J. (2003). *Selecting the right supply chain for a customer in project business* (PhD thesis). Helsinki University of Technology.

Collin, J., Eloranta, E., Holmstrom, J. (2009). How to design the right supply chains for your customers. *Supply Chain Management: An International Journal*, 14(6), 411-417.

Cousineau, D. and Cammerman, N. (2008). *The Snowy Mountain Hydro-electric and Irrigation Scheme: A situational and critical analysis*. QPAC Consulting.

Cook, W. D., Tone, K., Zhu, J. (2014). Data envelopment analysis: Prior to choosing a model, *OMEGA*, 44, 1-4.

Corbett, C., Van Wassenhove, L. (1993). Trade-offs? What trade-offs? Competence and competitiveness in manufacturing strategy. *California Management Review*, pp. 107–122.

Croom, S.R. (2001). The dyadic capabilities concept: examining the processes of key supplier involvement in collaborative product development. *European Journal of Purchasing and Supply Management*, 7(1), 29–37.

CS Energy. (2004). *2003-2004 Annual Report*. Retrieved from:

[http://www.csenergy.com.au/content-\(68\)-Media\\_centre.htm?cp=3/](http://www.csenergy.com.au/content-(68)-Media_centre.htm?cp=3/)

CS Energy. (2010a). *Annual Report*. Retrieved from:

[http://www.csenergy.com.au/content-\(68\)-Media\\_centre.htm](http://www.csenergy.com.au/content-(68)-Media_centre.htm)

CS Energy. (2011). *Annual Report*. Retrieved from:

[http://www.csenergy.com.au/content-\(68\)-Media\\_centre.htm](http://www.csenergy.com.au/content-(68)-Media_centre.htm)

CS Energy. (2015). *Annual Reports* [Online]. Retrieved from:

[http://www.csenergy.com.au/content-\(68\)-  
Corporate\\_Publications\\_Annual\\_Reports.htm](http://www.csenergy.com.au/content-(68)-Corporate_Publications_Annual_Reports.htm)

CS Energy. (2010b). *Statement of corporate intent*. Retrieved from:

[http://www.csenergy.com.au/media-\(68\)-\(82\)-\(247\)-  
Statement+of+Corporate+Intent+2009\\_2010.html](http://www.csenergy.com.au/media-(68)-(82)-(247)-Statement+of+Corporate+Intent+2009_2010.html)

CSIRO. (2013). *Change and choice: The future grid forum's analysis of Australia's potential electricity pathways to 2050*. CSIRO.

Dacruz, P. & Martin, G. (2011). The Smart Electricity Value Chain – Real-Time Pricing and Costing. White paper. *Invensys Operations Management*. Retrieved from:

[http://iom.invensys.com/EN/pdfLibrary/WhitePaper\\_Invensys\\_SmartElectricityValue  
Chain-RealTimePricing\\_04-11.pdf](http://iom.invensys.com/EN/pdfLibrary/WhitePaper_Invensys_SmartElectricityValueChain-RealTimePricing_04-11.pdf)

DCCEE (Department of Climate Change and Energy Efficiency). (2012). *Australian Government*. Retrieved from: <http://www.climatechange.gov.au/>

DiLorenzo, T. J. (1996). The myth of natural monopoly. *The Review of Austrian Economics*, 9(2), 43-58.

DSEWPC (Department of Sustainability, Environment, Water, Population and Communities). (2012). *Australian Government*. Retrieved from:

<http://www.environment.gov.au/epbc/compliance/index.html>.

Dubois, A., K. Hulthen, K., Pedersen, A.-C. (2004). Supply Chain and Interdependence: A Theoretical Analysis. *Journal of Purchasing and Supply Management*, 10(1), 3-9.

Duda, R. O., Hart, P. E. (1973). *Pattern Classification and Scene Analysis*. Chichester: Wiley.

Eadie, L. & Elliott, C. (2013). *Going solar: Renewing Australia's electricity options*. Centre for Policy Development.

Eising, J.W., van Onna, T., Floortje Alkemade, F. (2014). Towards smart grids: identifying the risks that arise from the integration of energy and transport supply chains. *Applied Energy*, 23, 448–55.

Elzen, B., Geels, F. W., Hoffman, P. S., & Green, K. (2004). Socio-technical scenarios as a tool for transition policy: An example from the traffic and transport domain. In B. Elzen, F. W. Geels & K. Green (Eds.). *System innovation and the transition to sustainability: Theory, evidence and policy* (pp. 251-281). Cheltenham: Edward Elgar.

Energy (2012). Australian Government. Retrieved from:

<http://australia.gov.au/topics/environment-and-natural-resources/energy>

Energy Efficient Exchange. (2015). How the energy market operates. Retrieved from:

<http://eex.gov.au/energy-management/energy-procurement/energy-pricing/how-the-energy-market-operates/>

Energy Supply Association of Australia. (2011). *Electricity and Gas Australia 2011*, ESAA.

Engineers Australia. (2016). Chronologies of Engineering Works in Queensland. *Engineering Heritage Queensland*. Retrieved from:

<https://www.engineersaustralia.org.au/queensland-division/chronology-engineering-works-queensland#PartC>

ESAA. (2012). *ESAA Objectives*. Retrieved from <http://www.esaa.com.au/>

Eslake, S. & Walsh, M. (2011). *Australia's productivity challenge*. Melbourne: Grattan Institute.

Et-Tolba, E. H., Afia, A. E. (2010). *A global modeling of electrical energy supply chain*. Presented at the International Conference on Models of Information and Communication Systems, 2010 ENSIAS, Morocco.

Everitt, B. S. (1994). *Statistical Methods for Medical Investigations*. London: Edward Arnold.

Fabrigar, L. R., Wegener, D. T., MacCallum, R. C., Strahan, E. J. (1999). Evaluating the use of exploratory factor analysis in psychological research. *Psychological Methods*, 4, 272–299.

Fare, R., Grosskopf, S., Pasurka, C. (1986). Effects on relative efficiency in electric power generation due to environmental controls. *Resources and Energy*, 8, 167-184.

Flint D. J. (2004). Strategic marketing in global supply chains: four challenges. *Industrial Marketing Management*, 33, 45-50.

Foxon, T.J. (2011). A coevolutionary framework for analysing a transition to a sustainable low carbon economy. *Ecological Economics*, 70, 2258–2267.

Froggatt, A., Lahn, G. (2010). *Sustainable energy security – strategic risks and opportunities for business*. Chatham House - Lloyd's 360 Risk Insight White Paper. Retrieved from:

[http://www.chathamhouse.org/sites/default/files/public/Research/Energy,%20Environment%20and%20Development/0610\\_froggatt\\_lahn.pdf](http://www.chathamhouse.org/sites/default/files/public/Research/Energy,%20Environment%20and%20Development/0610_froggatt_lahn.pdf)

Fung, P. (1999). Managing purchasing in a supply chain context—evolution and resolution. *Logistics Information Management*, 12(5), 362–366.

Fynes, B., Voss, C. (2002). The moderating effect of buyer–supplier relationships on quality practices and performance. *International Journal of Operations and Production Management*, 22(6), 589–613.

Gadde, L.E., Hakansson, H. (1994). The changing role of purchasing: reconsidering three strategic issues. *European Journal of Purchasing and Supply Management*, 1(1), 27–35.

Ganeshan, R., & Harrison, T. P. (1995). *An introduction to supply chain management*. The United States: Penn State University.

Gebauer, H., Gustafsson, A., Witell, L. (2011). Competitive advantage through service differentiation by manufacturing companies. *Journal of Business Research*, 64(12), 1270-1280.

Genus, A., Mafakheri, F. (2014). A neo-institutional perspective of supply chains and energy security: Bioenergy in the UK. *Applied Energy*, 123, 307-315.

Gorsuch, R. L. (1983). *Factor Analysis* (2<sup>nd</sup> ed). Hillsdale, NJ, USA: Lawrence Erlbaum Associates.

Gouveia, J.P., Dias, L., Martins, I., Seixas, J. (2014). Effects of renewables penetration on the on the security of Portuguese electricity supply. *Applied Energy*, 123, 438–47.



Gracceva, F., Zeniewski, P. (2014). A systemic approach to assessing energy security in a low-carbon EU energy system. *Applied Energy*, 123, 335–48.

Greene, W. (2005). Fixed and random effects in stochastic frontier models. *J. Prod. Anal.* 23 (1), 7–32.

Greis, N.P., Kasarda, J.D. (1997). Enterprise logistics in the information age. *California Management Review*, 39(3), 55–78.

Grubler, A., Aguayo, F., Gallagher, K., Hekkert, M., Jiang, K., Mytelka, L. (2012). Policies for the Energy Technology Innovation System (ETIS). *Global Energy Assessment – Toward a Sustainable Future* (Chapter 24, pp. 1665–744). Cambridge University Press.

Hahn, C.K., Watts, C.A., Kim, K.Y. (1990). The supplier development program: a conceptual model. *International Journal of Purchasing and Materials Management*, 26(2), 2–7.

Harland, C. M. (1996). Supply chain management: relationships, chains and networks. *British Journal of Management*, 7, S63-S80.

Harland, C., Brenchley, R., Walker, H. (2003). Risk in supply networks. *Journal of Purchasing and Supply Management*, 9(2), 51-62.

Harland, C.M., Lamming, R.C., Cousins, P.D. (1999). Developing the concept of supply strategy. *International Journal of Operations and Production Management*, 19(7), 650–673.

Hassini, E., Surti, C., Searcy, C. (2012). A literature review and a case study of sustainable supply chains with a focus on metrics. *Int. J. Production Economics*, 140, 69-82.

Hattori, T. (2002). Relative performance of US and Japanese electricity distribution: an application of stochastic frontier analysis. *J. Prod. Anal.* 18 (3), 269–284.

Helfert, G., Gemunden, H.G. (1998). *Relationship marketing team design: A powerful predictor for relationship effectiveness*. ISBM Report 6-1998. Institute for the Study of Business Markets, Pennsylvania State University, University Park, PA.

Heshmati, A., Lee, S., Hwang, W. (2012). Performance analysis of power plants under heterogeneous technologies with meta frontier framework. *Int J Economics and Management Eng*, 2(1), 5-14.

Hiebert, L. D. (2002). The determinants of the cost efficiency of electric generating plants: a stochastic frontier approach. *Southern Economic Journal*, 68(4), 935-946.

Hilmer, F. G., Rayner, M., Taperell. (1993). *National Competition Policy Review*. Canberra: Australian Government Publishing Service.

Hoggett, R. (2013). Supply chains and energy security. In C. Mitchell, J. Watson, J. Whiting (Eds.). *New challenges in energy security: the UK in a Multipolar World*. London: Palgrave MacMillan.

Hoggett, R. (2014). Technology scale and supply chains in a secure, affordable and low carbon energy transition. *Applied Energy*, 123, 296-306.

Huang, Y.J., Chen, Y.J., Yang, C.H. (2010). Cost efficiency and optimal scale of electricity distribution firms in Taiwan: an application of metafrontier analysis. *Energy Econ.* 32 (1), 15–23.

Hult, G. T. M., Ketchen, D. J. Jr., Cavusgil, S. T., Calantone, R. J. (2006). Knowledge as a strategic resource in supply chains. *Journal of Operations Management*, 24(5), 458–475.

Industry Commission. (1995). *The Growth And Revenue Implications Of Hilmer And Related Reforms*. Canberra, Australia. Retrieved from:

[http://www.pc.gov.au/\\_data/assets/pdf\\_file/0017/8810/hilmer.pdf](http://www.pc.gov.au/_data/assets/pdf_file/0017/8810/hilmer.pdf)

Infrastructure Australia. (2013). *Australia's Public Infrastructure; Update Paper: Balance Sheet Impacts of Sell to Build*. Commonwealth of Australia, Canberra, December 2013.

Investopedia. (2016a). *Production Efficiency*. Retrieved from:

[http://www.investopedia.com/terms/p/production\\_efficiency.asp](http://www.investopedia.com/terms/p/production_efficiency.asp)

Investopedia. (2016b). *Supply Chain*. Retrieved from:

<http://www.investopedia.com/terms/s/supplychain.asp>

Investopedia. (2016c). *Labour Productivity*. Retrieved from:

<http://www.investopedia.com/terms/l/labor-productivity.asp>

IPART. (2012). *Independent Pricing and Regulatory Tribunal*. Retrieved from: <http://www.ipart.nsw.gov.au>

IPCC. (2007). Chapter 10: Global Climate Projections. *Climate Change 2007: Working Group I: The Physical Science Basis*. Retrieved from: [http://www.ipcc.ch/publications\\_and\\_data/ar4/wg1/en/ch10.html](http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch10.html)

Jaraitè, J., Di Maria, C. (2012). Efficiency, productivity and environmental policy: a case study of power electricity generation in the EU. *Energy Econ.* 34 (5), 1557–1568.

Johansson, T. B. and Burnham, L. (1993). *Renewable energy: Sources for fuels and electricity*. Island Press.

Jones, C., Hesterly, W., Borgatti, S. (1997). A general theory of network governance: exchange conditions and social mechanisms. *Academy of Management Review*, 22(4), 911–945.

Joskow, P. L. (2007). Regulation of Natural Monopoly, Chapter 16. *Handbook of Law and Economics*, vol. 2, 1227-1348.

Kaiser, H.F., Rice, J. (1974). Little Jiffy, Mark IV. *Educational and Psychological Measurement*, 34, 111-117.

Kamerschen, D. R., Thompson, H. (Jr.) (1993). Nuclear and fossil fuel steam generation of electricity: differences and similarities. *Southern Economic Journal*, 60(1), 14-27.

Karoway, C. (1997). Superior supply chains pack plenty of byte. *Purchasing Technology*, 8 (11), 32–35.

Kathuria, R. (2000). Competitive priorities and managerial performance: a taxonomy of small manufacturers. *Journal of Operations Management*, 18, 627–641.

Kekre, S., Murthi, B.P.S., Srinivasan, K. (1995). Operating decisions, supplier availability and quality: an empirical study. *Journal of Operations Management*, 12, 387–396.

Kim, S.W. (2009). An investigation on the direct and indirect effect of supply chain integration on firm performance. *International Journal of Production Economics* 119(2), 328–346.

Kotabe, M., Martin, X., Domoto, H. (2003). Gaining from vertical partnerships: knowledge transfer, relationship duration, and supplier performance improvement in the U.S. and Japanese automotive industries. *Strategic Management Journal*, 24, 293–316.

Kounetas K., Mourtos, I. Tsekouras, K. (2009). Efficiency decompositions for heterogeneous technologies. *European Journal of Operational Research*, 199, 209-218.

Krugman, P. (2016). Defining and measuring productivity – OECD. Retrieved from:

<http://www.oecd.org/std/productivity-stats/40526851.pdf>

Kuosmanen, T. (2012). Stochastic semi-nonparametric frontier estimation of electricity distribution networks: application of the StoNED method in the Finnish regulatory model. *Energy Econ.* 34 (6), 2189–2199.

Kuosmanen, T., Kortelainen, M. (2012). Stochastic non-smooth envelopment of data: semiparametric frontier estimation subject to shape constraints. *J. Prod. Anal.* 38 (1), 11–28.

Kuosmanen, T., Saastamoinen, A., Sipiläinen, T. (2013). What is the best practice for benchmark regulation of electricity distribution? Comparison of DEA, SFA and StoNED methods. *Energy Policy* 61, 740–750.

Lambert, D. M. (2008). *An executive summary of supply chain management processes, partnerships, performance*. Sarasota, FL: Supply Chain Management Institute.

Lambert, D.M., Cooper, M.C. (2000). Issues in supply chain management. *Industrial Marketing Management*, 29, 65–83.

Lambert, D.M., Cooper, M.C., Pagh, J.D. (1998). Supply chain management: implementation issues and research opportunities. *The international journal of logistics Management*, 9(2), 1-20.

Lehner, F., Rastogi, A., Sengupta, S., Vuille, F., Ziem, S. (2012). *Securing the supply chain for renewable energy (RE-SUPPLY) – Final Report*. Retrieved from <http://iea-rettd.org/wpcontent/uploads/2012/11/RE-SUPPLY-final-report.pdf>

Liu, C. H., Lin, S. J., Lewis, C. (2010). Evaluation of thermal power plant operational performance in Taiwan by data envelopment analysis. *Energy Policy*, 38, 1049-1058.

Liu, Z., Nagurney, A. (2009). An integrated electric power supply chain and fuel market network framework: theoretical modeling with empirical analysis for New England. *Naval Research Logistics*, 56, 600-624.

Luenberger, D. (1992). Benefit function and duality. *J Math Econ*, 21, 461–481.

Lummus, R. R., Vokurka, R. J. (1999). Defining supply chain management: a historical perspective and practical guidelines. *Industrial Management & Data Systems*, 99(1), 11-17.

Mansson, A., Sanches-Pereira, A., Hermann, S. (2014). Biofuels for road transport: Analysing evolving supply chains in Sweden from an energy security perspective. *Applied Energy*, 123, 349-357.

MarketLine. (2014). *Australia - Power generation*. Re: 0125-2702.

Medori, D., Steeple, D. (2000). A framework for auditing and enhancing performance measurement systems. *International Journal of Operations and Production Management*, 20 (5), 520–533.

Miguel P.L.S., Brito L.A.L., Fernandes A.R., Tescari F.V.C.S., Martins, G.S. (2014). Relational value creation and appropriation in buyer-supplier relationships. *International Journal of Physical Distribution & Logistics Management*, 44(7), 559-576.

Miller, J.G., Roth, A.V. (1994). A taxonomy of manufacturing strategies. *Management Science*, 40(3), 285–304.

Min, H., Zhou, G. (2002). Supply chain modeling: past, present and future. *Computers and Industrial Engineering*, 43, 231-249.

Mitchell, C.H.C., Watson, J. (2013). New Challenges in Energy Security: the UK in a Multipolar World - Conclusions and Recommendations. In Mitchell, C., Watson, J., Whiting, J. (Eds.), *New Challenges in Energy Security: the UK in a Multipolar World*. Basingstoke: Palgrave MacMillan.

Moore, K.R. (1998). Trust and relationship commitment in logistics alliances: a buyer perspective. *International Journal of Purchasing and Material Management*, 34(1), 24–37.

Moran, A. (2003, November). Inquiry into privatisation of regional infrastructure and Government business enterprises. *Institute of Public Affairs Ltd. Energy Issues Paper*, 28.

Morgan, J.P., Zimmerman, S. (1990). Building world-class supplier relationships. *Purchasing*, 109, 62–84.

Mudie, A. (2015). *AGL Energy Ltd profit jumps by 18%: Should you buy?* Retrieved from:

<http://www.fool.com.au/2015/02/11/agl-energy-ltd-profit-jumps-by-18-should-you->

buy/

Mulhall, R.A., Bryson, J.R. (2014). Energy price risk and the sustainability of demand side supply chains. *Applied Energy*, 123, 327–34.

Nagurney, A., Matsypura, D. (2004). A supply chain network perspective for electric power generation, supply, transmission, and consumption, *Proceedings of the International Conference on Computing, Communications and Control Technologies*, 6, pp. 127–134, Austin, Texas, USA.

Nakano, M., Managi, S. (2008). Regulatory reforms and productivity: an empirical analysis of Japanese electricity industry. *Energy Policy*, 36 (1), 201–209.

Narus, J.A., Anderson, J.C. (1995). Using teams to manage collaborative relationships in business markets. *Journal of Business-to-Business Marketing*, 2, 17–47.

Näslund, D. and Hulthen, H. (2012). Supply chain management integration: a critical analysis. *Benchmarking: An International Journal*, 19(4/5), 481 – 501.

*National Inventory Report 2014 (revised)*. (2016). Department of the Environment and Energy, Commonwealth of Australia, Vol. 1.

Neely, A.D. (1999). The performance measurement revolution: why now and what next? *International Journal of Operations and Production Management*, 19(2), 205–228.

Nelson, T., Simshauser, P., Orton, F., Kelley, S. (2012). Delayed Carbon policy certainty and electricity prices in Australia: a concise summary of subsequent research, *Journal of applied economics and policy*, 31(1), 132-135.

Norris, M., Lecavalier, L. (2009). Evaluating the Use of Exploratory Factor Analysis in Developmental Disability Psychological Research. *J Autism and Developmental Disorders*, 40, 8–20.

NSW Office of Water, 2009. Final report: Five-year review of the Snowy Hydro water license. Licence review, May 2002 to May 2007. Department of Environment, Climate Change and Water. Sydney.

O'Donnell, C. J., Rao, D. S. P., Battese, G. E. (2008). Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. *Empirical Economics*. 34, 231-225.

Oh, D.-h. (2015). Productivity growth, technical change and economies of scale of Korean fossil-fuel generation companies, 2001–2012: A dual approach. *Energy Economics*, 49, 113 – 121.

Oil and Gas Review. (2012). *The Energy Oil and Gas Review*. Retrieved from <http://oilandgasreview.com.au/word/energy-supply-chain-reinforces-links>

Omrani, H., Gharizadeh Beiragh, R., Shafiei Kaleibari, S. (2015). Performance assessment of Iranian electricity distribution companies by an integrated cooperative game data envelopment analysis principal component analysis approach. *Electrical Power and Energy Systems*, 64, 617 – 625.

Orea, L., Kumbhakar, S. (2004). Efficiency measurement using stochastic frontier latent class model. *Empir. Econ.* 29 (1), 169–183.

Origin. (2012a). *About Origin*. Retrieved from:

<http://www.originenergy.com.au/2/About>

Origin. (2012b). *Annual Report*. Retrieved from:

<http://www.originenergy.com.au/1770/Results-reports/>

Origin. (2012c). *ASX/Media Release*. Retrieved from:

<http://www.originenergy.com.au/news/article/asxmedia-releases/1455>

Origin. (2012d). *Business Strategy*. Retrieved from:

[http://reports.originenergy.com.au/2011/sustainability/about\\_origin/business\\_strategy](http://reports.originenergy.com.au/2011/sustainability/about_origin/business_strategy)

[1/](#)

Origin. (2012e). *Origin reports strong operational performance*. Retrieved from:

<http://www.originenergy.com.au/news/article/asxmedia-releases/1268>

Origin. (2015a). *Sharing Economic Benefits*. Retrieved from:

<http://www.originenergy.com.au/about/our-approach/society/sharing-economic-benefits.html>

Origin. (2015b). *Reports and Results*. Retrieved from:

<http://www.originenergy.com.au/about/investors-media/reports-and-results.html>

Origin Sustainability Report. (2012). *Origin Energy*. Retrieved from:

<http://www.originenergy.com.au/384/Searchresults?query=Origin%27s+Supply+Chain&section=site&start=10>

Pearson, P.J.G., Foxon, T.J. (2012). A low carbon industrial revolution? Insights and challenges from past technological and economic transformations. *Energy Policy*, 50, 117-27.

Perl, M., Mewett, L. (2008). The Cooper Basin – Australia’s central gas hub. *Gas Today*, Retrieved from:

[http://gastoday.com.au/news/the\\_cooper\\_basin\\_-\\_australias\\_central\\_gas\\_hub/283](http://gastoday.com.au/news/the_cooper_basin_-_australias_central_gas_hub/283).

Perloff, J. (2012). *Microeconomics*, 7<sup>th</sup> ed, Pearson Education, London, UK.

Pierce, J. (2012). *The Australian national electricity market: Choosing a new future*. Presented at World Energy Forum, Quebec City, Canada, 2012.

Portugal-Pereira, J., Esteban, M. (2014). Implications of paradigm shift in Japan’s electricity security of supply: a multi-dimensional indicator assessment. *Applied Energy*, 123, 424–34.

Prasada Rao, D.S. (2016). *Efficiency and productivity measurement: Stochastic frontier analysis*, School of Economics, The University of Queensland, Australia. Retrieved from:

[https://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=7&ved=0ahUKEwiuls7l487OAhWMJpQKHRLSD7AQFghGMAY&url=http%3A%2F%2Fwww.eukle.ms.net%2Fdata%2Fworkshop%2Fslides%2FLecture%25204\\_Day\\_3\\_Stochastic%2520Frontier%2520Analysis.ppt&usg=AFQjCNGkCC47xQs1g8bF9IPocNgIM2LAhw](https://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=7&ved=0ahUKEwiuls7l487OAhWMJpQKHRLSD7AQFghGMAY&url=http%3A%2F%2Fwww.eukle.ms.net%2Fdata%2Fworkshop%2Fslides%2FLecture%25204_Day_3_Stochastic%2520Frontier%2520Analysis.ppt&usg=AFQjCNGkCC47xQs1g8bF9IPocNgIM2LAhw)

Primo, M.A.M., Amundson, S.D. (2002). An exploratory study of the effects of supplier relationships on new product development outcomes. *Journal of Operations Management*, 20, 33–52.

Productivity Commission (2012, February). *AGL’s Productivity Commission Issues*. Retrieved from [http://www.pc.gov.au/\\_\\_data/assets/pdf\\_file/0016/116620/sub027-electricity.pdf](http://www.pc.gov.au/__data/assets/pdf_file/0016/116620/sub027-electricity.pdf)

Quezada, G., Grozev, G., Seo, S., Wang, C.-H. (2014). The challenge of adapting centralised electricity systems: peak demand and maladaptation in South East Queensland, Australia. *Reg Environ Change*, 14, 463–473.



Rabe-Hesketh, S., Everitt, B. (2007). *A Handbook of Statistical Analyses Using Stata* (4<sup>th</sup> ed.). NY, USA: Chapman & Hall/CRC.

Radstaak, B.G., Ketelaar, M.H. (1998). *Worldwide Logistics: The Future of Supply Chain Services*. Hague, Netherlands: Holland International Distribution Council.

Ragatz, G.L., Handfield, R.B., Peterson, K.J. (2002). Benefits associated with supplier integration into new product development under conditions of technology uncertainty. *Journal of Business Research*, 55, 389–400.

Ragatz, G.L., Handfield, R.B., Scannell, T.V. (1997). Success factors for integrating suppliers into new product development. *Journal of Product Innovation Management*, 14(3), 190–202.

Ramblingsdc. (2012). *Wind power in Australia*. Retrieved from [http://ramblingsdc.net/Australia/WindPower.html#Major\\_wind\\_farms\\_in\\_Australia](http://ramblingsdc.net/Australia/WindPower.html#Major_wind_farms_in_Australia)

Reck, R.F., Long, B.G. (1988). Purchasing: a competitive weapon. *Journal of Purchasing and Materials Management*, 24(4), 3–6.

Reserve Bank of Australia. (2011). *How Are Electricity Prices Set in Australia?* Retrieved from <http://www.rba.gov.au/foi/disclosure-log/pdf/101115.pdf>

Reuters. (2012). *AGL Energy LTD Purchases Remaining Shares in Great Energy Alliance Corporation Pty Limited*. Retrieved from <http://www.reuters.com/finance/stocks/AGK.AX/key-developments/article/2565682>

Rice Jr, J. B., Spayd, P. W. (2005). *Investing in supply chain security: Collateral benefits*. Special Report Series: IBM Center for the Business of Government, 1-34.

Robins, B. (2014). Snowy Hydro bulks up with \$600m energy buy. *Sydney Morning Herald*. Retrieved from <http://www.smh.com.au/business/snowy-hydro-bulks-up-with-600m-energy-buy-20140914-10goeo.html>

Roelich, K., Dawson, D., Purnell, P., Knoeri, C., Revell, R. and Busch, J. (2014). Assessing the dynamic material criticality of infrastructure transitions: a case of low carbon electricity. *Applied Energy*, 123, 378–86.

Saari, S. (2006). Productivity: Theory and measurement in business. *European Productivity Conference* (EPC2006). Finland, 30 August – 1 September 2006.

Saastamoinen, A., Kuosmanen, T. (2016). Quality frontier of electricity distribution: Supply security, best practices, and underground cabling in Finland. *Energy Econ.* 53, 281–292.

Sahay, B.S. (2003). Understanding trust in supply chain relationships. *Industrial Management & Data Systems*, 103(8/9), 553-564.

Sakun, B., Himangshu, P. (2008). Moderating Effects of Environmental Uncertainty on Supply Chain Integration and Product Quality: An Empirical Study of Thai Automotive Industry. *IJAIM*, 2, 49-61.

Santos, F. C. A. (2000). Integration of human resource management and competitive priorities of manufacturing strategy. *International Journal of Operations and Production Management*, 20(5), 610–628.

Schultz, J., Sharpe, O. (2014). The role of regulation in Australia's future energy mix. *Environment and Climate Change Law Library*.

Sena, V. (2003). The frontier approach to the measurement of productivity and technical efficiency. *Economic Issues*, 8(2), 71-97.

Shah, J. (2009). *Supply chain management: text and cases*. India: Pearson Education.

Shin, H., Collier, D.A., Wilson, D.D. (2000). Supply management orientation and supplier/buyer performance. *Journal of Operations Management*, 18(3), 317–333.

Simar, L., Zelenyuk, V. (2011). Stochastic FDH/DEA estimators for frontier analysis. *Journal of Productivity Analysis*, 36(1), 1–20.

Sioshansi, F.P. (2013). *Evolution of global electricity markets: New paradigms, new challenges and new approaches*. Academic Press.

Skea, J., Anandarajah, G., Chaudry, M., Shakoor, A., Strachan, N. and Wang, X. (2011). Energy futures: the challenges of decarbonisation and security of supply. In J. Skea, P. Ekins, M. Winskel (Eds), *Energy 2050: making the transition to a secure low carbon energy system*. London: Earthscan.

Skea, J., Ekins, P. and Winskel, M. (2011). Introduction. In J. Skea, P. Ekins, M. Winskel, (Eds), *Energy 2050: making the transition to a secure low carbon energy system*. London: Earthscan.

Skea, J., Wang, X. and Winksel, M. (2011). UK Energy in an era of globalisation: trends, technologies and environmental impacts. In J. Skea, P. Ekins and M Winksel (Eds.), *Energy 2050: Making the Transition to a Secure Low Carbon Energy System*, 11.

Snowy Hydro. (2011). *Annual Report*. Retrieved from <http://www.snowyhydro.com.au/corporate/annual-reports/>

Snowy Hydro. (2012a) *Nem Operations*. Retrieved from <http://www.snowyhydro.com.au/business/nem-operation>

Snowy Hydro. (2012b). *Electricity Supply Chain: Optimising your Energies* (Report). Published by Snowy Hydro Limited. Retrieved from <http://www.snowyhydro.com.au/>

Snowy Hydro. (2012c). Corporate. Retrieved from:

<http://www.snowyhydro.com.au/corporate/>

Snowy Hydro SouthCare. (2012). Snowy Hydro Limited. Retrieved from:

<http://www.snowyhydrosouthcare.com.au/support/sponsorship/profiles/#.UApWgGFo2jY>

Snowy Hydro Ltd. (2013) *Investing in the Snowy Scheme – Finalisation of Tumut 3 Power Station Modernisation*. Retrieved from:

<http://www.snowyhydro.com.au/blog/2013/05/16/investing-in-the-snowy-scheme-finalisation-of-tumut-3-power-station-modernisation/>

Snowy Hydro Ltd. (2014). *Statement of Corporate Intent 2014*. Retrieved from <http://www.snowyhydro.com.au/wp-content/uploads/2011/11/Statement-of-Corporate-Intent-2014.pdf+&cd=1&hl=en&ct=clnk&gl=au&client=safari>

Snowy Hydro Ltd. (2015a). *Annual reports*. Retrieved from:

<http://www.snowyhydro.com.au/corporate/annual-reports/>

Snowy Hydro Ltd. (2015b). *Scheme Modernisation commences at Tumut 1*. Retrieved from:

<http://www.snowyhydro.com.au/blog/2015/03/30/scheme-modernisation-commences-at-tumut-1/>

Snowy Hydro Ltd. (2015c). *Business*. Retrieved from:

<http://www.snowyhydro.com.au/business/>

Snowy Hydro Ltd. (2015d). *Cloud seeding program*. Retrieved from:

<http://www.com.au/waterenvironment/cloud-seeding/cloud-seeding-how-does-it-work/>

Snowy River Environmental Flows. (2011, November). *Department Sustainability, Environment, Water, Population and Communities*.

Stevens, J. (2002). *Applied Multivariate Statistics for the Social Sciences* (4<sup>th</sup> ed.). Mahwah, NJ, USA: Lawrence Erlbaum Associates.

Stock, G. N., Greis, N. P., Kasarda, J. D. (2000). Enterprise logistics and supply chain structure: the role of fit. *Journal of Operations Management*, 18(5), 531–547.

Sueyoshi, T., Goto, M. (2011). DEA approach for unified efficiency measurement: assessment of Japanese fossil fuel power electricity generation. *Energy Econ.* 33 (2), 292–303.

Sueyoshi, T., Goto, M., Ueno, T. (2010). Performance analysis of US coal-fired power plants by measuring three DEA efficiencies. *Energy Policy*, 38, 1675-1688.

Sunil, C. P. (2011). *Supply chain management: strategy, planning and operation* (4th ed). New Jersey: Prentice Hall.

Sustainable Water Strategy. (2012). *Technical Paper 7: Management of the Snowy Hydro Electric Scheme*. Retrieved from <http://www.water.vic.gov.au>

Swamidass Winskel, M., Anandarajah, G., Skea, J., Jay, B. (2011). Accelerating the development of energy supply technologies: the role of research and innovation. In J. Skea, P. Ekins, M. Winskel (Eds), *Energy 2050: making the transition to a secure low carbon energy system*. London: Earthscan.

Tan, K.C., Kannan, V.R., Handfield, R.B. (1998). Supply chain management: supplier performance and firm performance. *International Journal of Purchasing and Material Management*, 34(3), 2–9.

Tan, K.C., Kannan, V.R., Handfield, R.B., Ghosh, S. (1999). Supply chain management: an empirical study of its impact on performance. *International Journal of Operations and Production Management*, 19(10), 1034–1052.

Taylor, M., Forster, C. (2014). *Australia: Privatisation of electricity networks*, New South Wales, Australia: Mondaq Ltd. Retrieved from:

<http://www.mondaq.com/australia/x/326754/Oil+Gas+Electricity/Privatisation+of+electricity+networks+New+South+Wales+Australia>

The World Bank. (2016). *Electric power transmission and distribution losses (% of output)*. Retrieved from: <http://data.worldbank.org/indicator/EG.ELC.LOSS.ZS>

Treasury (2012a). *Early retirement of power plants*. Retrieved from <http://archive.treasury.gov.au/>

Troutt, M. D., Gribbin, D. M., Shanker, M. S., Zhang, A. (2003). Maximum performance efficiency approaches for estimating best practice costs. In Wang, J. (ed), *Data Mining: Opportunities and Challenges*. Idea Group Publishing, London, UK, p. 239-259.

Troutt, M. D., Hu, M., Shanker, M. & Acar, W. (2001). Frontier versus ordinary regression models for data mining. In Parag C. Pendharkar (ed.), *Managing data mining technologies in organizations: Techniques and applications*. Hershey, PA: Idea Group Publishing Co.

Turton, H. (2004). *Greenhouse gas emissions in industrialized countries: Where does Australia stand?* The Australia Institute, Canberra, Australia.

Unruh, G.C. (2002). Escaping carbon lock-in. *Energy Policy*, 30, 317–25.

Van Weele, A.J., Rozemeijer, F.A. (1996). Revolution in purchasing: building competitive power through proactive purchasing. *European Journal of Purchasing and Supply Management*, 2(4), 153–160.

Wang, X.-H., Cong, R.-G. (2012). Electric power supply chain management addressing climate change. *Procedia Engineering*, 29, 749-753.

WebFinance Inc. (2016). *Business Dictionary*. Retrieved from:

<http://www.businessdictionary.com/definition/productivity.html>

Wee, H. M., Yang, W. H., Chou, C. W., Padilan, M. V. (2012). Renewable energy supply chains, performance, application barriers, and strategies for further development. *Renewable and Sustainable Energy Reviews*, 16(8), 5451-5465.

Weiss, J. and Kelly, P. (2008). *Embracing Supply Chain Complexity as a Competitive Advantage*. Pheonix AZ: Honeywell International Inc.

Yeager, K., Dayo, F., Fisher, B., Fouquet, R., Gilau, A., Rogner, H.-F., Haug, M., Hosier, R., Miller, A., Schnitteger, S. (2003). Chapter 6: Energy and Economy. *GEA, 2012: Global Energy Assessment - Toward a Sustainable Future*, Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria. Retrieved from:

[http://www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/GEA\\_Chapter6\\_economy\\_lowres.pdf](http://www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/GEA_Chapter6_economy_lowres.pdf)

# Appendix 1

**Table A1.1. The complete database for the 30 EGDCs**

ID	Company Name	Type	Year	Number of Employees	PP&E (\$)	EBITDA (\$)	Revenue (\$)	Output (GWh)	Total Employee Cost (\$)	Cost of Sales (\$)
1	Western Power Corporation	D	7	2246	3606473000	374750000	797187123		78078000	702915008
1	Western Power Corporation	D	8	2509	4255939000	438230000	932361024		109950000	817889024
1	Western Power Corporation	D	9	2813	5091847000	551659000	1102639000		116891000	926182016
1	Western Power Corporation	D	10	2943	5690747000	565421000	1107472000		170548000	991996032
1	Western Power Corporation	D	11	3013	6234810000	592326000	1375944000	19600	173759008	652964992
1	Western Power Corporation	D	12	3276	6893678000	615232000	1485471000	19434	185703008	701158016
3	Sydney County Council (Ausgrid)	D	7	5389	5964300	780000000	2889000000	32000	382310016	218500000
3	Sydney County Council (Ausgrid)	D	8	5649	6706201	890000000	3096321000	20985	440500992	495000000
3	Sydney County Council (Ausgrid)	D	9	5908	7701712	1246000000	3339201000	30400	420800000	535500000
3	Sydney County Council (Ausgrid)	D	10	5941	8715500	1391000000	3980400000	30691	428400992	725110016
3	Sydney County Council (Ausgrid)	D	11	5868	9949715	1527000000	2635601000	29276	426612000	749702976
3	Sydney County Council (Ausgrid)	D	12	5713	11305012	2092000000	2926011000	26316	493100000	618200000
4	ActewAGL	D	7	1375	1229400000	107391000	509438000	2967	141231008	125140000
4	ActewAGL	D	8	1396	804710000	185235000	770932000	3011	141523008	139258000
4	ActewAGL	D	9	1496	803944000	190105000	798762000	3038	143718000	143652992
4	ActewAGL	D	10	1129	863018000	217181000	847597000	2967	152590000	149659008

4	ActewAGL	D	11	1117	929509000	200888000	737563000	3017	154987008	575281024
4	ActewAGL	D	12	1170	985680000	198762000	722146000	3116	107915000	566406976
8	Energy Developments Ltd	G	7	323	617390000	34481000	176981000	2464	26231000	71142000
8	Energy Developments Ltd	G	8	366	685307000	100255000	195771000	2100	32270000	91577000
8	Energy Developments Ltd	G	9	385	681527000	97220000	239385000	2800	38327000	112063000
8	Energy Developments Ltd	G	10	392	646399000	111122000	253754000	3200	41360000	121151000
8	Energy Developments Ltd	G	11	396	568622000	111680000	249297000	3100	46028000	116685000
8	Energy Developments Ltd	G	12	400	643696000	127931000	311041000	3150	54501000	164483008
9	Endeavour Energy	D	7	2593	3066117000	466739000	1368075000	9741	119839000	926753024
9	Endeavour Energy	D	8	2760	3355096000	496761000	1705953000	11785	117983000	1404509056
9	Endeavour Energy	D	9	2871	3669490000	492817000	1852002000	12099	125969000	1253368064
9	Endeavour Energy	D	10	2888	4275733000	588980000	977006000	11076	228819008	730785024
9	Endeavour Energy	D	11	2925	4711941000	711567000	1136535000	17501	231050000	795340992
9	Endeavour Energy	D	12	2824	5555956000	755657000	1224992000	16506	286819008	721286016
10	Powerlink	D	7	843	3915299000	297954000	583858000	46083	46276000	313768992
10	Powerlink	D	8	887	4599079000	355956000	611635000	47904	48197000	326948000
10	Powerlink	D	9	906	5219870000	374721000	682814000	47825	50450000	360364992
10	Powerlink	D	10	952	5636418000	436560000	734992000	46216	75258000	388624992
10	Powerlink	D	11	986	6074115000	478732000	824133000	46246	86474000	388555008
10	Powerlink	D	12	1028	6682846000	533902000	921959000	45871	89730000	416155008
11	Ergon Energy	D	7	4192	5459912000	1789000000	3173200000		185102000	514910016
11	Ergon Energy	D	8	4489	6224300000	658130000	2598300000	15547	174600000	521120992
11	Ergon Energy	D	9	4634	6900610000	685742000	2279600000	15722	170100000	555752000
11	Ergon Energy	D	10	4630	7495000000	769200000	2203100000	15678	174500000	508612000
11	Ergon Energy	D	11	4752	8768120000	836100000	2528120000	14544	214700000	634000000



11	Ergon Energy	D	12	5060	9219300000	1103000000	2691201000	15212	244200000	682201024
12	Country Energy	D	7	4238	3248644000	313108000	2097058000	3261	306768000	195258000
12	Country Energy	D	8	4353	3660278000	350290000	2307967000	3750	386735008	201002000
12	Country Energy	D	9	4534	4115367000	352895000	2489877000	4800	349396992	201038000
12	Country Energy	D	10	4573	5901274000	360264000	2648496000	5352	382884992	297979008
12	Country Energy	D	11	4720	6278650000	426452000	2464319000	5395	404568992	407169984
12	Country Energy	D	12	4892	6792198000	530276000	2416958000	5532	485047008	457934016
13	ENERGEX	D	7	3732	6012215000	586700000	1261000000	20500	212600000	255800992
13	ENERGEX	D	8	3794	6125312000	651000000	1403000000	22210	232510000	303612992
13	ENERGEX	D	9	3733	7054000000	623600000	1336252000	23175	208100000	306900000
13	ENERGEX	D	10	3784	8021800000	727720000	1467900000	23365	212100992	345710016
13	ENERGEX	D	11	3835	9067600000	912310000	1736400000	22565	218600000	390700000
13	ENERGEX	D	12	3804	10048700000	1060520000	2005000000	22144	232800000	471000000
14	Aurora Energy	D	7	1031	1002112000	110490000	814052000	10484	119655000	111546000
14	Aurora Energy	D	8	1081	1065413000	110942000	902842000	10536	125532000	109906000
14	Aurora Energy	D	9	1222	1450046000	103827000	1018193000	10154	152215008	132089000
14	Aurora Energy	D	10	1323	1609393000	120778000	1197014000	11026	170654000	199348000
14	Aurora Energy	D	11	1230	1697295000	140732000	1392101000	11977	156264000	201067008
14	Aurora Energy	D	12	994	1747139000	129822000	1492900000	12356	123152000	205784992
15	Ausgrid	D	7	4423	5964300000	862000000	2889000000	30335	353800000	237370000
15	Ausgrid	D	8	4484	6706200000	852000000	3096312000	32000	377700000	253560000
15	Ausgrid	D	9	4181	7701701000	890000000	3339200000	32000	415409984	271432000
15	Ausgrid	D	10	5435	8715511000	1246000000	1997900000	30400	406214016	149960992
15	Ausgrid	D	11	6190	9949700000	1391000000	2635600000	30691	426600992	186230000
15	Ausgrid	D	12	5998	11305200000	1527000000	2926100000	29276	493100000	132194000

16	Infratil Energy	GD	7	420	1640000000	356000000	655100000	1941	32521000	39600000
16	Infratil Energy	GD	8	490	1846231000	316000000	961700000	2018	33561000	42523000
16	Infratil Energy	GD	9	532	2304530000	356000000	1333100000	2381	33962000	44218000
16	Infratil Energy	GD	10	515	2433000000	363000000	711000000	2755	33714000	48569000
16	Infratil Energy	GD	11	508	3777000000	471000000	897000000	3280	33432000	58000000
16	Infratil Energy	GD	12	556	3914000000	520000000	1008900000	3760	34692000	63800000
17	Pacific hydro	G	7	251	695000000	70961000	115852000	1121	17987000	33364000
17	Pacific hydro	G	8	223	727007000	69156000	112326000	1063	16452000	30326000
17	Pacific hydro	G	9	240	763010000	75132000	118767000	1190	17066000	32935000
17	Pacific hydro	G	10	291	889000000	86759000	114836000	1535	18930000	38192000
17	Pacific hydro	G	11	314	895005000	81179000	151904000	1435	26474000	45376000
17	Pacific hydro	G	12	278	936020000	112023000	196560000	1900	28269000	50840000
18	Meridian	G	7	800	6315000000	476400000		12678	55284000	55300000
18	Meridian	G	8	800	6432000000	373900000		11908	69088000	33265000
18	Meridian	G	9	806	6743000000	512400000		12237	76000000	34000000
18	Meridian	G	10	804	8207000000	641700000		13862	87258000	53000000
18	Meridian	G	11	800	7720000000	659900000		13652	89493000	56740000
18	Meridian	G	12	800	7963000000	476600000		10996	79589000	69271000
19	Duet	G	7	360	4083909000	435000000	902987000	7880	33962000	22600000
19	Duet	G	8	363	4498556000	475000000	971828000	7925	34120000	28840000
19	Duet	G	9	366	4835859000	631000000	1042938000	7929	34325000	28840000
19	Duet	G	10	366	5209179000	611603000	1154410000	8114	34256000	29210000
19	Duet	G	11	368	5319868000	641484000	1212261000	8071	35652000	29850000
19	Duet	G	12	367	5473171000	638235000	1222080000	8134	35562000	29750000
20	Hydro Tasmania	G	7	795	3520541000	113493000	491581000	9062	84868000	30250000

20	Hydro Tasmania	G	8	819	4056372000	224185000	470008000	8269	88574000	32940000
20	Hydro Tasmania	G	9	860	4146346000	291206000	625737000	7881	88822000	29270000
20	Hydro Tasmania	G	10	844	4161631000	236434000	726933000	8167	100763000	29850000
20	Hydro Tasmania	G	11	791	4414220000	312521000	812772000	9273	104660000	31900000
20	Hydro Tasmania	G	12	994	4484569000	456819000	1051131000	9538	104802000	31840000
23	Stanwell	G	7	360	1256102000	222926000	515357000	8036	38063000	190624992
23	Stanwell	G	8	368	1356215000	167621000	540949000	8713	38201000	194920992
23	Stanwell	G	9	388	1318296000	265903000	670367000	7845	38616000	177820000
23	Stanwell	G	10	400	1297523000	205527000	662995000	8063	45577000	252199008
23	Stanwell	G	11	396	1039244000	278140000	563558000	6328	45677000	223814000
23	Stanwell	G	12	775	2213369000	935720000	1319045000	6796	96135000	226039008
24	Macquarie Generation	G	7	610	2545239000	449000000	1082037000	2513	50392000	65406000
24	Macquarie Generation	G	8	617	3587348000	771000000	1161734000	2628	55230000	71028000
24	Macquarie Generation	G	9	631	3494221000	318000000	1217233000	2699	58525000	87107000
24	Macquarie Generation	G	10	621	3358923000	500000000	1165256000	2457	63704000	83321000
24	Macquarie Generation	G	11	628	3214322000	397000000	1018369000	2142	64340000	77806000
24	Macquarie Generation	G	12	621	2098041000	367000000	973576000	2452	68808000	73811000
25	Eraring Energy	G	7	650	5812000000	182400000	816100000	11020	50861000	19000000
25	Eraring Energy	G	8	685	6402000000	272400000	730600000	11035	48790000	29000000
25	Eraring Energy	G	9	400	5161000000	270200000	630600000	9948	50772000	29000000
25	Eraring Energy	G	10	414	5395000000	220000000	596600000	9691	53907000	28210000
25	Eraring Energy	G	11	406	10313000000	220100000	583947000	10259	56954000	29130000
25	Eraring Energy	G	12	415	10895000000	225700000	615779000	10653	65593000	30567000
26	Power & Water Corporation	G	7	236	1156326000	307000000	527028000	1790	18923000	21000000
26	Power & Water Corporation	G	8	244	1365231000	499200000	600222000	1821	21900000	22800000

26	Power & Water Corporation	G	9	228	1291189000		495119000	1868	21300000	27960000
26	Power & Water Corporation	G	10	290	1464137000		612742000	1946	27190000	32700000
26	Power & Water Corporation	G	11	309	2061419000		652007000	1918	30900000	33921000
26	Power & Water Corporation	G	12	345	2436180000		438286000	1939	30600000	20703000
27	Infigen Energy	G	7	115	1197296000	126500000	171900000	540	16561000	10227000
27	Infigen Energy	G	8	164	4887995000	193000000	254300000	804	16864000	13952000
27	Infigen Energy	G	9	120	3396213000	215200000	285319000	875	15962000	14931000
27	Infigen Energy	G	10	180	3110894000	195500000	324934000	1137	16989000	15972000
27	Infigen Energy	G	11	174	2460112000	145569000	285319000	1335	16895000	17937000
27	Infigen Energy	G	12	185	2430105000	140513000	283473000	1402	16942000	18863000
28	Redbank Energy	G	7	623	1540044000	118449000	472357000	3575	52273000	25263000
28	Redbank Energy	G	8	659	2531415000	241412000	819778000	3650	94191000	27140000
28	Redbank Energy	G	9	687	2144808000	185900000	676140000	3032	136746000	23549000
28	Redbank Energy	G	10	750	2156417000	196646000	547050000	3035	130500000	23159000
28	Redbank Energy	G	11	723	2854125000	198237000	631740000	2963	126326000	22817000
28	Redbank Energy	G	12	693	2957100000	189100000	626740000	2658	123521000	21637000
29	Delta Electricity	G	7	713	2134000000	244000000	874100000	21952	48727000	59272000
29	Delta Electricity	G	8	726	2346000000	212000000	1008438000	24054	39768000	67329000
29	Delta Electricity	G	9	741	2726000000	146000000	983136210	23756	49788000	73884000
29	Delta Electricity	G	10	719	2554545000	189000000	1042500000	21999	49274000	67653000
29	Delta Electricity	G	11	671	4928091000	176000000	1109772000	21501	47037000	73725000
29	Delta Electricity	G	12	653	3883377000	118300000	874047000	19916	57769000	68671000
30	Electricity Trust of South Australia	GD	7	502	2791542000	507000000	913500231	11300	65431000	67010000
30	Electricity Trust of South Australia	GD	8	530	2913435000	541000000	971633536	11379	72573000	61280000
30	Electricity Trust of South Australia	GD	9	552	3082387000	632000000	1052991000	11447	90015000	72980000

30	Electricity Trust of South Australia	GD	10	549	3329047000	669000000	1126708000	11320	92657000	75300000
30	Electricity Trust of South Australia	GD	11	574	4616527000	719000000	1272633000	11093	102808000	101660000
30	Electricity Trust of South Australia	GD	12	541	5053956000	613000000	1384141000	11307	99684000	109500000
31	Horizon Energy	GD	7	209	1003261000	52713000	109518000	792	14875000	16215000
31	Horizon Energy	GD	8	251	1005418000	58549000	117311000	832	17392000	17210000
31	Horizon Energy	GD	9	343	1001259000	65917000	133808000	463	19989000	17965000
31	Horizon Energy	GD	10	381	1042364000	68040000	170763000	970	31536000	18281000
31	Horizon Energy	GD	11	415	1066472000	116084000	194555000	974	35919000	18650000
31	Horizon Energy	GD	12	439	1162318000	132860000	225174000	1950	40219000	19863000
32	Verve Energy's	G	7	610	1817188000	111972000	1068881000	12012	23199000	18321000
32	Verve Energy's	G	8	593	1752592000	116865000	1039091000	11753	26168000	16232000
32	Verve Energy's	G	9	612	1630267000	111567000	1062500000	11891	29562000	17564000
32	Verve Energy's	G	10	622	1679722000	124326000	1249763000	8899	33930000	14232000
32	Verve Energy's	G	11	595	1744880000	129548000	1304692000	8834	37061000	13265000
32	Verve Energy's	G	12	642	2023442000	135697000	1352829000	9788	35935000	15632000
33	CS Energy	GD	7	578	2142000000	135000000	616349000	13996	59450000	49886000
33	CS Energy	GD	8	569	2087000000	198000000	739924000	15426	60387000	54010000
33	CS Energy	GD	9	640	2058000000	216000000	781349000	16675	71830000	56520000
33	CS Energy	GD	10	673	2012000000	218000000	712987000	17046	80289000	57870000
33	CS Energy	GD	11	675	1833000000	189000000	615384000	15636	82983000	51640000
33	CS Energy	GD	12	454	1967000000	191000000	438220000	17138	58768000	29390000
34	Origin Energy	GD	7	530	6655000000		75237000	1620	61180000	22356000
34	Origin Energy	GD	8	530	6772000000	65000000	89559000	1550	64400000	21000000
34	Origin Energy	GD	9	613	7018000000	107000000	132000000	1670	77740000	25000000
34	Origin Energy	GD	10	585	9168000000	183000000	235000000	2360	84410000	52000000

34	Origin Energy	GD	11	644	10313000000	327000000	474000000	5310	101200000	147000000
34	Origin Energy	GD	12	758	10895000000	400000000	589000000	5900	132250000	106260000
35	Snowy Hydro	GD	7	443	1985000000	348453000	594026000	4633	65877000	39624000
35	Snowy Hydro	GD	8	433	2038000000	429000000	651779000	3762	76055000	35420000
35	Snowy Hydro	GD	9	462	2091000000	512000000	711016000	3333	85212000	37110000
35	Snowy Hydro	GD	10	440	2175000000	581000000	781900000	3983	92200000	37620000
35	Snowy Hydro	GD	11	443	2271000000	719000000	952600000	5094	100700000	41370000
35	Snowy Hydro	GD	12	439	1786000000	580000000	836300000	3210	101600000	46600000
36	AGL	GD	7	532	1268000000	69000000	509600000	14076	34040000	41325000
36	AGL	GD	8	447	2815000000	38800000	655800000	14640	51750000	43884000
36	AGL	GD	9	481	2109000000	50200000	854200000	14641	55200000	47756000
36	AGL	GD	10	477	2240000000	44980000	356500000	15518	61640000	53279000
36	AGL	GD	11	467	2281000000	52230000	558700000	15174	63710000	57064000
36	AGL	GD	12	460	5185000000	62850000	204700000	15410	69000000	59184000

G = generation EGDC; D = distribution EGDC; GD = generation and distribution EGDC